APPENDIX B

SHIP SIMULATION STUDIES

1 Introduction

The Brewerton Channel Eastern Extension and the Tolchester Channel are part of the Baltimore Harbor & Channels 42-Foot Project authorized by the River & Harbor Act of 1958. The project provides, in part, for deepening and widening the approach channels leading to the Chesapeake and Delaware (C&D) Canal from 27 feet deep and 400 feet wide to 35 feet deep and 600 feet wide (Figures 1 and 1A).

The Brewerton Channel Eastern Extension is a straight channel approximately five nautical miles long, extending from the Brewerton Channel, main approach channel to Baltimore Harbor, eastward across the Chesapeake Bay. Deepening and widening of the channel was deferred until 1986 when the State of Maryland could provide a suitable dredged material placement area. At the State's request, the channel was constructed to 35 feet deep and 450 feet wide in 1986. Additional widening of the turn at the eastern end and widening of the eastern nautical mile of the channel from 450 to 600 feet was accomplished in 1991 to allow inbound ships additional channel width to recover from the 72-degree turn and to allow outbound ships additional width to set up for the turn.

The Tolchester Channel is approximately six nautical miles long, extending from just south of the Brewerton Channel Eastern Extension, northeasterly along the eastern side of the Chesapeake Bay, following the deeper water along the historical river bed of the Susquehanna River. The dredged portion of the Tolchester Channel ends approximately 2,000 feet south of the Tolchester Marina where there is a 2-nautical mile long area of the Chesapeake Bay which is naturally deeper than 35 feet and wider than 600 feet. The Inland Waterway to the C&D Canal starts north of the naturally deep water.

State of Maryland regulations require all foreign flag vessels to take a pilot. Pilotage for most large vessels in the project area is, therefore, provided by the Association of Maryland Pilots. American flag vessels operating in coastwise trade may utilize Federal Pilots in lieu of Maryland Pilots. These vessels comprise a small percentage of the large vessels using the waterway.

Problem Identification

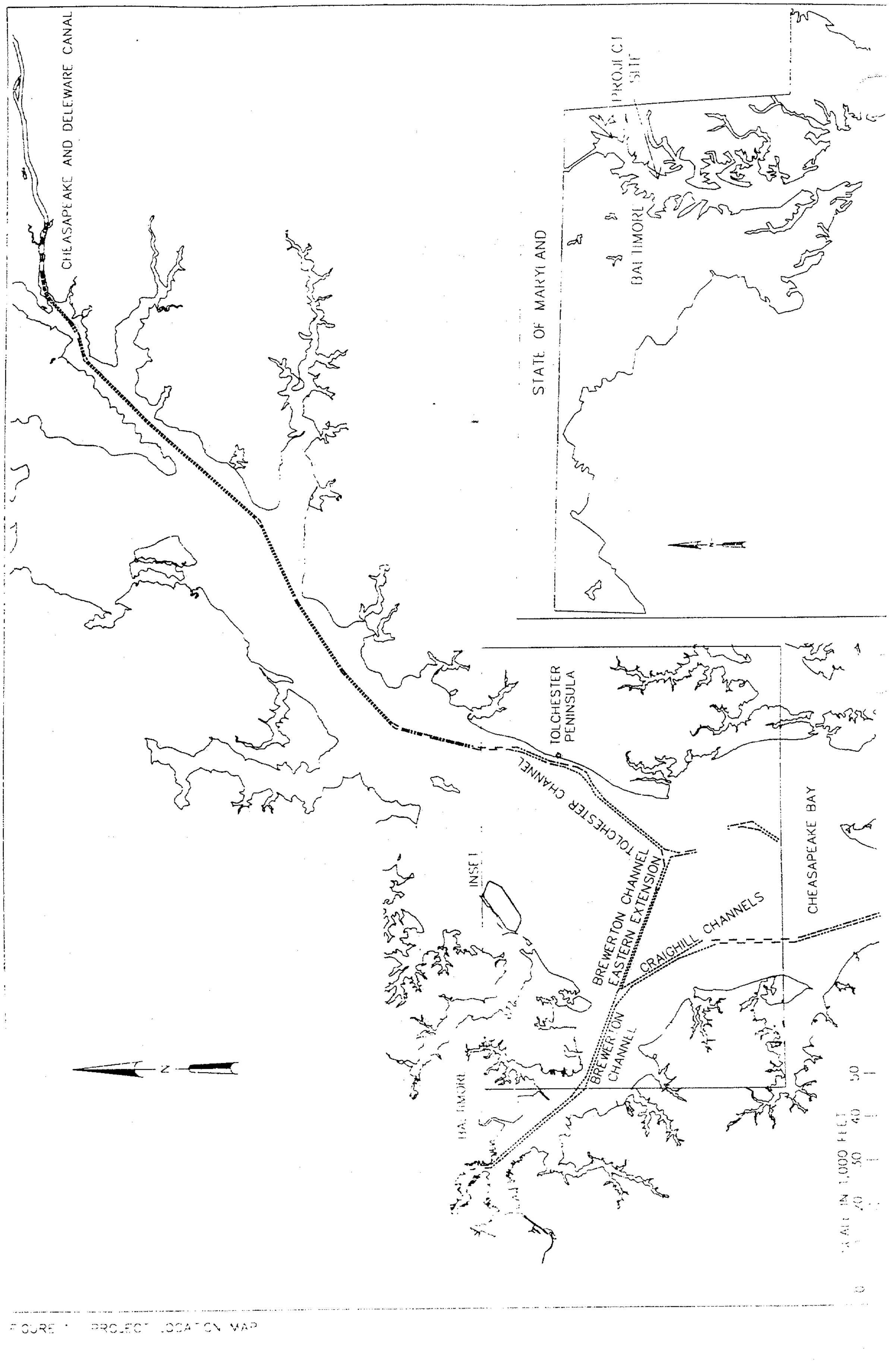


FIGURE 1 PROJECT LOCATION MAP

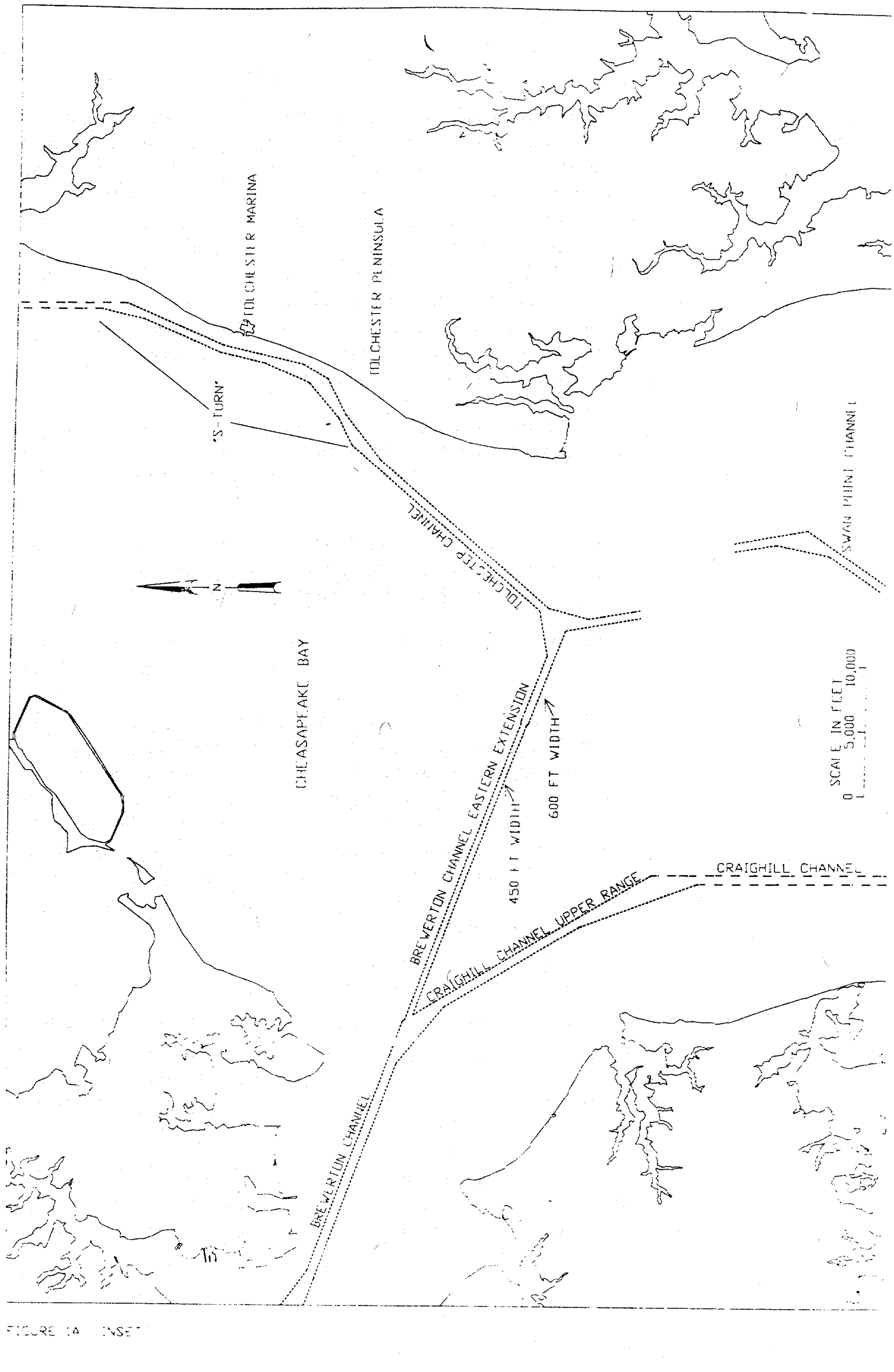


FIGURE 1A INSET

Brewerton Channel Eastern Extension. Prior to deepening of the Brewerton Channel Eastern Extension from 27 to 35 feet deep, deeper draft ships had to navigate a more circuitous route to the south using the main approach channels (Craighill Channels) and the Swan Point Channel to transit between the Port of Baltimore and the C&D Canal. This increased the length of the trip by 15 nautical miles and the transit time by 60 to 75 minutes. Some larger vessels still choose to use the longer route due to perceived navigation difficulties, adverse weather conditions or to avoid meeting/passing situations. Some vessels and carriers choose not to use the C&D Canal system and opt for the longer route through the southern Chesapeake Bay for the same reasons.

The Brewerton Channel Eastern Extension is perpendicular to tidal currents in the area. Both flood and ebb flows can be greater than one knot. Whether or not a large ship will use the extension channel in strong currents is left to the pilot's discretion.

Two way traffic is limited in the 450-ft extension channel. The Association of Maryland Pilots has imposed a 160-ft combined beam restriction for vessels meeting in the 450-ft portion of extension channel.

Tolchester Channel. Navigation problems in the Tolchester channel occur primarily in the "S-Turn." The "S-Turn" is a series of five course changes in a three nautical mile section of the channel. The channel follows the naturally deep water which comes close to the shore and rises abruptly to shallow water outside the eastern edge of the channel. While the turns have been widened several times in this area, maneuvering a ship through this many different headings in such a short reach requires the pilot have accurate knowledge of the ship's position at all times during the turn. The turn is even more difficult to navigate in ice because the buoys are less visible, the ice tends to pile up in this area of the Bay because of the wind, currents and geomorphology of the bay, and because there are no range lights for the channel.

Proposed Channel Improvements

To alleviate these navigation concerns, the Maryland Port Administration and the Association of Maryland Pilots have requested the United States Army Engineer District, Baltimore (the District) widen the Brewerton Channel Eastern Extension from 450 feet wide to its authorized width of 600 feet, and straighten the Tolchester Channel "S-Turn."

Brewerton Channel Eastern Extension. To accommodate two-way traffic for vessels with a combined beam greater than 160 feet and to allow larger vessels to use the channel, the District suggested that the Brewerton

Channel Eastern Extension be modeled for widths of 500, 550 and 600 feet. Proposed widening of the channel would be done symmetrically about the channel centerline since the channel has fixed range lights at the eastern end of the channel and the channel is an extension of the Brewerton Channel which has fixed range lights at the western end of the channel.

Tolchester Channel. The District and the Waterways Experiment Station (WES) developed a proposed re-alignment of the "S-turn". The new alignment reduced the number of channel segments from five to two. The proposed alignment is shown in Figure 2.

Purpose and Scope

In order to evaluate the proposed plans for channel improvement, WES conducted a navigation study for both channels. The navigation study consisted of ship simulation modeling, two-dimensional hydrodynamic modeling (Talbot, in preparation), sedimentation modeling (Teeter, in preparation), and a differential global positioning system (DGPS) survey. Results from the protoytpe DGPS survey are included in this report as Appendix A.

The purpose of the navigation study was to determine the effects of the proposed improvements on navigation and to optimize the required channel width and alignment required to safely and efficiently navigate the study area.

Description of WES Ship/Tow Simulator

The WES Ship/Tow Simulator is a "real-time" marine simulator which can function as either a deep-draft or a shallow-draft simulator. "Real-time" means that the movements on the simulator require the same amount of time as they do in real life. The Brewerton Channel Eastern Extension and Tolchester Channel study used experienced pilots from the Association of Maryland Pilots to navigate a simulated vessel through the simulation models of the waterway. These pilots were familiar with the project local and the vessels navigating the area.

Visual cues given to the mariner during a test run are: an animated "out-the-window" view of the project area; radar displays; and a precision navigation display which includes vessel speed (both absolute and relative to the water), lateral velocities, heading, rudder angle, engine speed, wind, and a rate-of-turn indicator. A schematic diagram of the WES Ship/Tow Simulator is shown in Figure 3. Figure 4 shows the WES Ship/Tow Simulator during testing of the Brewerton/Tolchester Navigation Project.

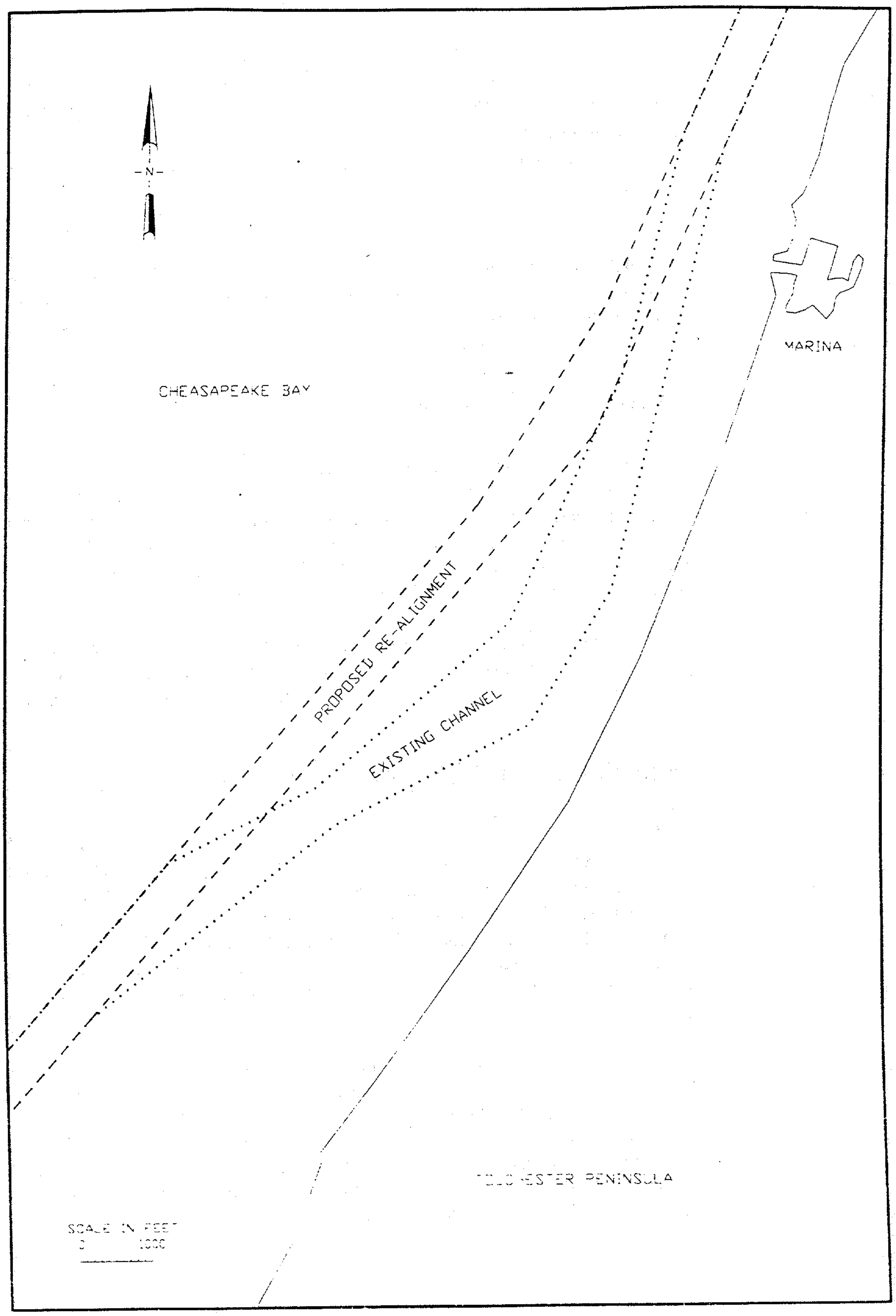


FIGURE 2 PROPOSED TOLCHESTER CHANNEL MODIFICATION

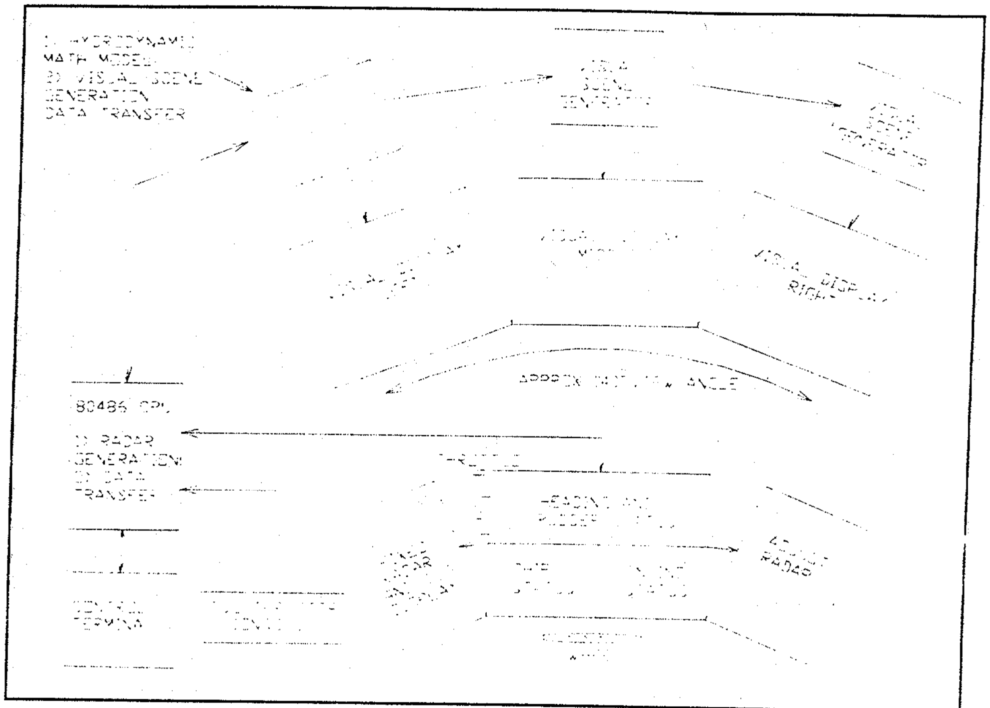


Figure 3: Schematic diagram of WES Ship/Tow Simulator

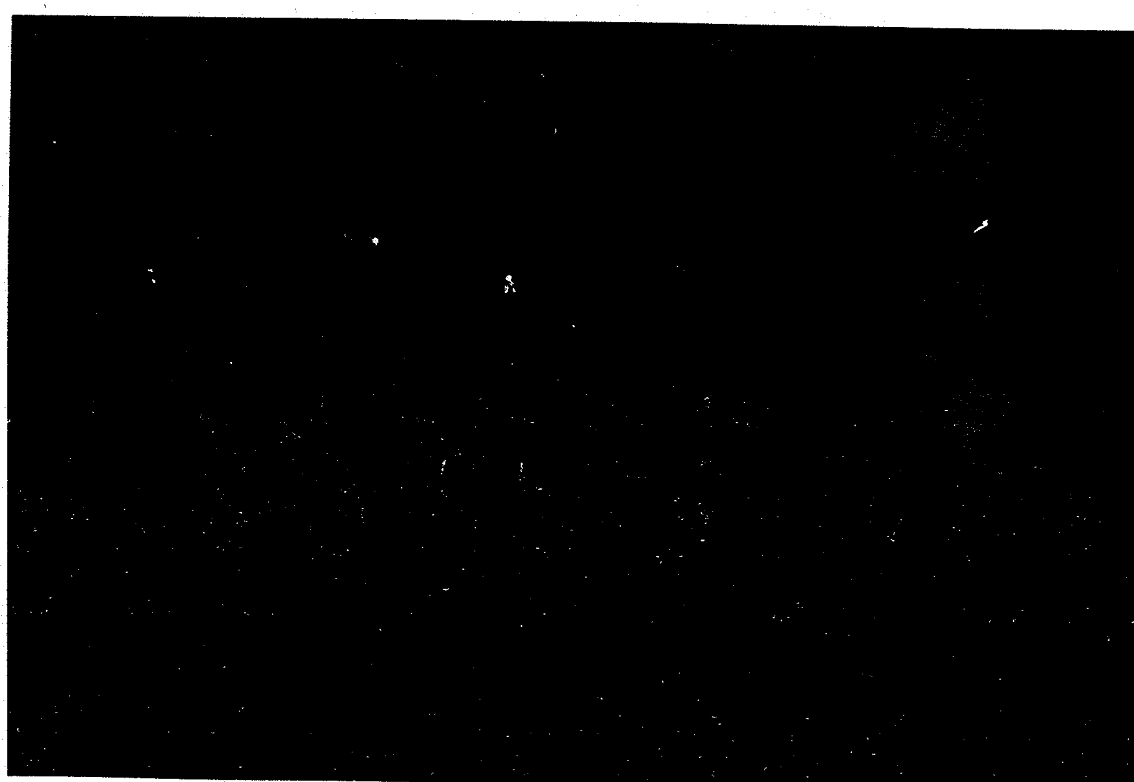


Figure 4. WES Ship/Tow Simulator, outbound ship meeting inbound ship in Brewerton Channel Eastern Extension.

Mariners operate the simulator by issuing engine, rudder, or tug/thruster commands. The engine and rudder commands are input to the hydrodynamic program at the ship's console by either the mariner or a helmsman. Tug or thruster commands are input by an operator stationed at the tug console. The hydrodynamic program calculates the resultant vessel movement based on these inputs and environmental conditions. The ship's motion is then shown on the visual and radar displays. If necessary, the mariner responds to this movement by issuing additional commands. This interaction of the mariner and the simulation process is known as "man-in-the-loop".

The visual scene is generated in three dimensions: north-south, east-west, and vertical elevation. As the ship progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position on the ship's bridge for viewing. The graphics hardware used for the Brewerton/Tolchester Navigation Project was a stand-alone computer connected with the main computer to obtain information for updating the viewing position and orientation. This information includes parameters such as vessel heading, rate of turn, forward and lateral velocity, and position.

Two radar displays are provided for the mariner's use during a simulator run. The radar image is a continuously updated plan view of the vessel's position relative to the surrounding area. The variable scaled radar display provides three different ranges to enable the pilot to choose the scale needed. A second radar screen with a fixed 0.25-mile range is also provided to display assist tug forces. The tug force appears on the radar screen as a vector either pushing or pulling the simulated vessel. The magnitude of the vector is scaled to represent the tug force being applied.

2 Data Development

Data Required

In order to simulate the study area, it was necessary to develop information relative to five types of input data:

a. The channel database contains dimensions for the existing channel and the proposed channel modifications. It includes the channel cross sections, bank slope angle, overbank depth, ice thickness, initial conditions, and autopilot track-line definition.

b. The visual scene database is composed of three-dimensional images of principal features of the simulated area, including the aids to navigation, docks, land features, and buildings.

c. The radar database contains the features for the plan view of the study area.

d. The current pattern data in the channel include the magnitude and direction of the current and the water depth for each cross section defined in the channel database.

e. The ship data file contains characteristics and hydrodynamic coefficients for the test vessels.

The test scenarios, design vessels, and environmental conditions were selected in order to test the existing and proposed channels in the "maximum credible adverse situation," that is, the worst conditions under which the harbor would maintain normal operations. This approach provides a built-in safety factor when analyzing the results. The existing channels were tested in order to provide a base with which to compare tests conducted in the proposed channels, and to provide a basis for comparison of conditions by the pilots involved in the testing.

Simulator Databases

Test File. The test file contains initial conditions (ship speed and heading, rudder angle, and engine setting) for the simulation and geographical coordinates for the channel alignment. The channel is defined in terms of cross sections located to coincide with changes in channel alignment and current direction and magnitude. Also included in the test file are the steepness and overbank depth (water depth at the top of the side slope) adjacent to the channel. These data are used by the computer to calculate bank effect forces on the test vessels. Specifications of other external forces such as wind and ice are also included in this file.

For the Brewerton Channel Eastern Extension / Tolchester Channel project the simulator channel cross sections were placed approximately 500 ft apart except where the bends occurred or where channel width changed. Since the channels were fairly uniform, the simulator cross sections did not vary in spacing significantly. The simulator program handles the transition between cross sections on an interpolative basis.

Water depths for the simulator were based on authorized project depths. For the simulated existing channel, the water depth represented the existing condition taken from the most recent hydrographic survey furnished by the District. Also, bank slopes and overbank depths were obtained from the latest District dredging survey. These data are used in the calculation of ship hull bank forces. Briefly, bank forces occur when a ship travels close to a submerged bank, and the resulting effect is characterized by a movement toward the bank and a bow-out rotation away from the bank.

A wind simulating approximately 25 knots from the northwest was imposed on all simulation tests in the project area. There was no sheltering from wind effects anywhere in the study area.

The ability to model the ice effects on ships transiting frozen waterways was added to WES Ship/Tow Simulator for this study (Ankudinov, 1995b). An ice thickness of one ft was used for the Tolchester Channel. Ice was not simulated for the Brewerton Channel Eastern Extension because ice does not accumulate there as much and is not as much of a navigation concern because the channel is straight and the range lights can be used when the buoys are moved off station or obscured by ice.

Visual Scene File. The scene data base comprises several data files containing geometrical information enabling the graphics computer to generate the simulated scene of the study area. The computer hardware and software used for visual scene generation are separate from the main computer of the ship simulator. The main computer provides motion and orientation information to a stand-alone graphics computer for correct vessel positioning in the scene, which is then viewed by the pilot. Operators view the scene as if they are standing on the bridge of a ship looking toward the ship's bow in the foreground. View direction can be changed during simulation for the purpose of looking at objects outside of the relatively narrow straight-ahead view.

Aerial photographs, navigation charts, and photos taken during the reconnaissance trip provided the basic data for generation of the visual scene. All land masses in the vicinity of the navigation channel were included in the scene. All aids to navigation (ATONS) in the vicinity of the study area were included. Informal ATONS, such as fire towers, silos, specific buildings, and any other object that the pilots use as a reference were also included in the visual scene. In addition to the man-made and topographical features in the vicinity, the visual scene included a perspective view of the bow of the ship from the pilot's viewpoint. Visual databases for all design ships were developed at WES for use in the simulation.

Ice simulations were conducted by changing the water surface color from blue to a glaring white. Only the top portion of the buoys were visible during ice runs.

Radar File. The radar file contains coordinates defining the border between land and water and significant man-made objects, such as docks and aids to navigation. These data are used by another graphics computer that connects the coordinates with straight lines and displays them on a terminal. The objects viewed comprise visual information that simulates shipboard radar.

Current File. The current file contains current magnitude and direction and water depth for each of eight points across each of the cross sections defining the channel alignment. Current data for a ship simulation study are usually obtained from physical or numerical models. The model bathymetry was modified for generation of currents for the two proposed conditions.

Channel currents for the Brewerton Channel Eastern Extension / Tolchester Channel project were derived from the TABS-2 model study conducted at WES (Talbot, in preparation). All currents tested in the simulation study were tidal driven. There are no areas of fresh water inflow near the navigation channel tested. Test currents were the maximum spring ebb and flood tides.

Ship File. The ship file contains characteristics and hydrodynamic coefficients for the test vessel. These data are the computer's definition of the ship. The coefficients govern the reaction of the ship to external forces, such as wind, current, waves, banks, underkeel clearance, ship/ship interaction, and internal controls, such as rudder and engine revolutions per minute (rpm) commands.

The design vessel for this study was a containership with a length of 965 ft, beam of 106 ft and a draft of 33 ft. This ship was used for transits both into and out of Baltimore. This ship was chosen based on current traffic and the District's economic analysis of future shipping business and operations. A few additional runs were made in the Brewerton Channel Eastern Extension with a 610- x 94- x 33-ft bulk carrier. The numerical ship models for the Brewerton

Channel Eastern Extension / Tolchester Channel study were developed under contract by a naval architect (Ankudinov, 1988 and 1995a).

3 Navigation Study

Validation

The simulation was validated 21 - 25 August and 27 September, 1995 with the assistance of two pilots licensed for the project area. The second date was necessary because of problems displaying a second ship in the visual scene during the first validation effort. The seceond ship was required to validate ship-to-ship interaction forces. The following information was verified and fine tuned during validation:

a. Wind effects.

b. Bank conditions.

c. Currents.

d. Ship engine and rudder response

e. Ship to ship interaction

f. Ice

g. The visual scene and radar image of the study area.

(1) Location of all aids to navigation.

(2) Location of buildings visible from the vessel.

Validation was accomplished by having the pilots maneuver the simulated vessel through the entire study area at slack tide. Once the bank effects were validated tidal currents, wind and ice were added to the scenarios. Special attention was given by the pilot to the response of the ship due to external forces.

Problem areas were isolated and the prototype data for these areas were examined. The model was then adjusted and further simulation runs were then undertaken through the problem areas, and if necessary, additional adjustment was made. This process was repeated until the pilot was satisfied that the simulated vessel response was similar to that of an actual vessel in the prototype.

Preliminary Testing

A preliminary test program was undertaken to evaluate the three proposed widths for the Brewerton Channel Eastern Extension. Based on these preliminary tests, the 500-ft width was eliminated from consideration as inadequate. Results from the 500 ft wide channel simulations revealed many more instances of grounding than occured in either the 550- or 600-ft channel.

Test Scenarios

The test scenarios, design vessels, and environmental conditions were selected to test the existing and proposed channels in the "maximum credible adverse situation", that being the worst conditions under which the harbor would maintain normal operations. This approach provides a built in safety factor when analyzing the results. The existing channels were tested to provide a base with which to compare tests conducted in the proposed channels and to provide a basis of comparison of conditions to the pilots involved in the testing.

The environmental conditions were identical for both the Brewerton Channel Eastern Extension and the Tolchester Channel Simulations. Simulation tidal currents were the maximum strengh of ebb and flood. A wind of 25 knots from the north-west was used for all simulations.

Two-way traffic was simulated during each run. Two different meeting locations were used for the existing condition, Tolchester Channel runs so that the meeting could occur in the "S-turn" and the straight reach.

Procedures

Each day of testing began with practice runs to allow the pilots to familiarize themselves with the simulator equipment. Tests were conducted in a random order. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. The skill gained at operating the simulator could show the plans to be easier than they might really be.

During each run, the characteristic parameters of the ship were automatically recorded every 5 seconds. For runs made in the entrance channel with waves, the parameters were recorded every one second. These parameters included the position of the ship's center of gravity, speed, rpm of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

4 Study Results

An analysis of the ship simulation study results for the Brewerton Channel Eastern Extension will be given first, followed by the results for the Tolchester Channel. This analysis will included ship track plots, vessel parameter plots, and pilot questionnaires.

Track plots show the position and orientation of the ships as recorded every 10 seconds during the tests. The track plots are plotted on a plan view of the project area showing the navigation channel, ATONS and shoreline. This provides a record of the path the ships followed throughout a test run. Important clearance values are printed on the track plot. These document instances where the ship left the channel, or came extremely close to the channel edge. Included on each track plot is a scaled inset showing the clearances when the ships where nearly abeam, i.e. side-by-side in the channel. The clearance shown in the inset were taken when the ships were closest to each other. Therefore, the inset's clearance values are not necessarily at the same point in the run as clearance values printed on the complete track plot.

Navigation parameters included in this report are rudder angle, engine speed, and ship speed. Navigation parameters are plotted versus distance along track. The distance along track is the distance traveled projected perpendicularly to a command reference. Figures showing the reference line for each test reach are provided in this report.

Summary tables containing clearances shown in the track plot when the ships are abeam during each test condition are also included. The clearance values are averaged for each condition. For averaging, a zero value is used for negative clearances. This is done to keep a high negative clearance from skewing the averages.

Brewerton Channel Eastern Extension

Individual ship track and parameter plots of all runs conducted in the Brewerton Channel Eastern Extension are presented in Plates 1-72. The distance along track reference line is shown in Figure 5. Average clearance

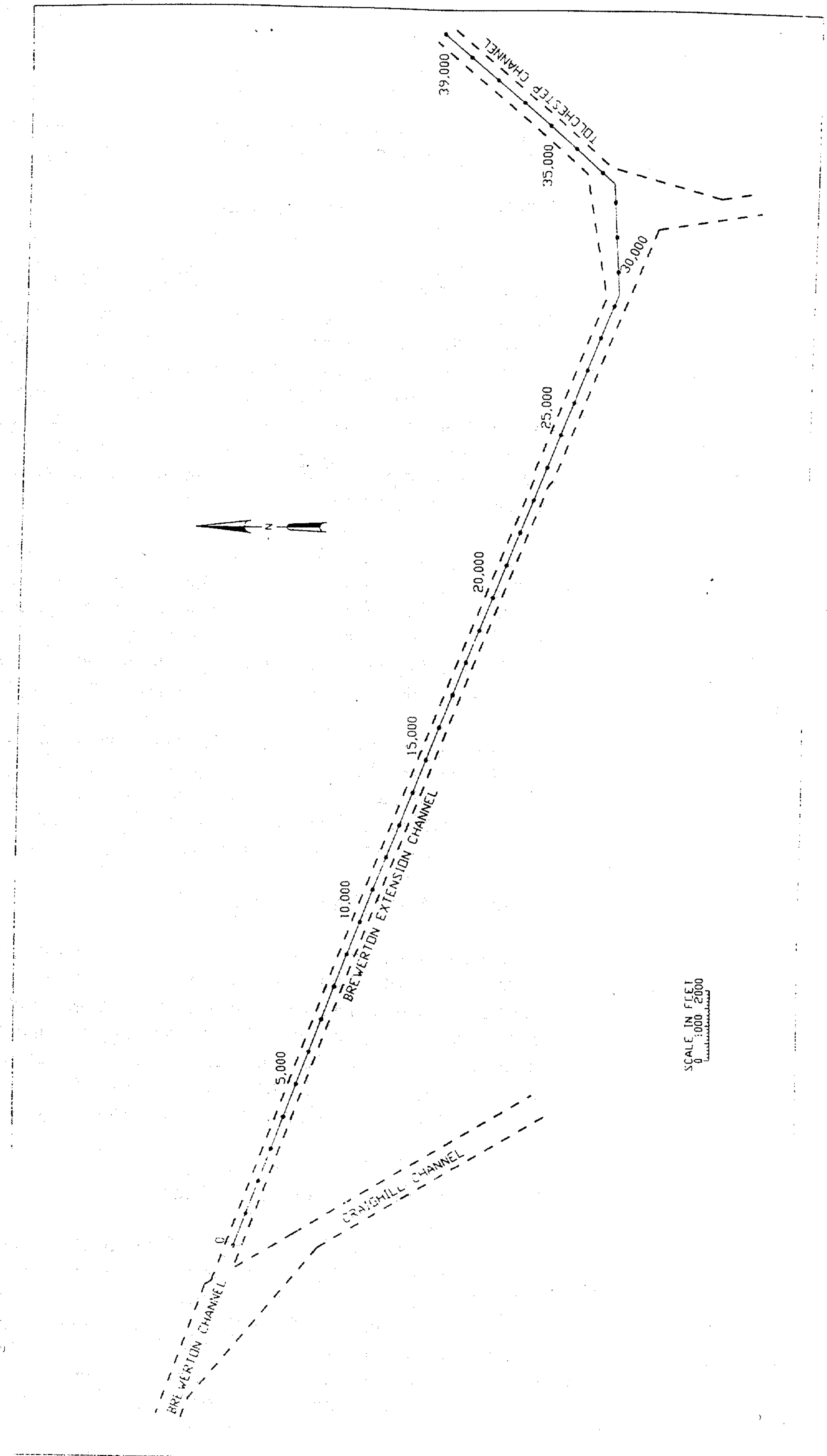


Figure 3 Distance Along Track, Brewerton Channel Eastern Extension

values at time of meeting are discussed in the following paragraphs and are presented in Table 1 for ebb tide and Table 2 for flood tide.

Existing Conditions, Ebb Tide

The ship track and parameter plots for ships transiting the existing 450 ft wide channel with ebb tide are presented in Plates 1-12. The pilots strategy during the meeting was to maximize the distance between the ships by keeping close to the bank. None of these runs were completed without one or both of the vessels leaving the channel, even if only by a few feet. One outbound ship (Plate 9) completely ran aground. The resulting combination of bank force and ship-to-ship interaction made the ship completely leave the channel on the northern side, thus ending the run. The average clearance values were 91.2 ft between the ships, 49.7 ft from the inbound ship to the channel edge, and 22.7 ft from the outbound ship to the channel edge.

During two runs (Plates 1 and 7), the outbound ship left the channel on the east side while turning into the Tolchester Channel. Comparisons of the parameter plots for these two runs (Plates 2 and 8) and those of a successful run (Plate 4) show that the pilots who left the channel use port rudder about 1,000 ft later than the successful pilot. These groundings were unrelated to the meeting situation in the 450-ft Brewerton Channel Eastern Extension.

One inbound run (Plate 9) left the south side of the channel by 66 ft after turning into the extension channel. The rudder angle plot for this run (Plate 10) shows that the pilot either did not apply the starboard rudder as soon, or let off the rudder sooner than the other pilots. This resulted in the ebb tide, northwest wind, and ship's momentum carrying the ship out of the channel.

Proposed 550-ft Channel, Ebb Tide

The ship track and parameter plots for ships transiting the proposed 550 ft wide channel with ebb tide are presented in Plates 13-24. There was one adverse incident and another near incident in the extension channel during these tests. One inbound run (Plate 19) left the extension channel and another inbound run (Plate 13) had a clearance of 2 ft just after meeting. The average clearance values were 125.2 ft between the ships, 90.3 ft from the inbound ship to the channel edge, and 55.7 ft from the outbound ship to the channel edge.

Proposed 600-ft Channel, Ebb Tide

The ship track and parameter plots for ships transiting the proposed 600 ft wide channel with ebb tide are presented in Plates 25-36. There were three adverse incident and another near incident in the extension channel during these tests. One inbound run (Plate 25) left the extension channel by 26 ft in the existing 600-ft wide section of the channel prior to the meeting. Two runs had negative or low clearances at the time of meeting. One (Plate 27) came to within 3 ft of the channel edge and the other (Plate 35) left the channel by 2 ft.

All three of these instances were a result of the pilots attempting to keep the two ships as far apart as possible.

One inbound ship (Plate 33) ran aground because the pilot stayed near the center of the channel, thus reducing the clearance between the vessels. The ship-to-ship interaction was therefore increased, forcing the inbound ship to leave the channel by 12 ft just after the meeting occurred. The average clearance values were 143.2 ft between the ships, 88.3 ft from the inbound ship to the channel edge, and 64.7 ft from the outbound ship to the channel edge.

Existing Conditions, Flood Tide

The ship track and parameter plots for ships transiting the existing 450 ft wide channel with flood tide are presented in Plates 37-48. None of these runs were completed without one or both of the vessels leaving the channel. The average clearance values were 116.5 ft between the ships, 11.5 ft from the inbound ship to the channel edge, and 61.0 ft from the outbound ship to the channel edge.

Proposed 550-ft Channel, Flood Tide

The ship track and parameter plots for ships transiting the proposed 550 ft wide channel with flood tide are presented in Plates 49-60. One outbound ship (Plates 53 and 54) used 15 to 25 degrees starboard rudder to run along the southern edge of the extension channel. The most that this ship left the channel was 21 ft, shortly before meeting the inbound vessel. The average clearance values were 144.3 ft between the ships, 46.8 ft from the inbound ship to the channel edge, and 93.7 ft from the outbound ship to the channel edge.

Proposed 600-ft Channel, Flood Tide

The ship track and parameter plots for ships transiting the proposed 600 ft wide channel with flood tide are presented in Plates 61-72. There were four instances of negative clearance. Two of these groundings (Plates 63 and 65) were because the outbound ship set up on the south side of the channel in an attempt to keep as far away from the inbound ship as possible and crossed the southern channel edge prior to meeting the inbound ship. One inbound ship (Plate 71) left the northern side of the channel by 24 ft while keeping away from the outbound ship, which remained near the center of the channel. The other instance of negative clearance (Plate 67) occurred when the outbound ship stayed near the center of the channel and grounded on the northern side of the channel after meeting the inbound ship. The average clearance values were 133.7 ft between the ships, 70.8 ft from the inbound ship to the channel edge, and 106.0 ft from the outbound ship to the channel edge.

Existing Channel, Bulk Carrier, Flood Tide

During the second week of testing, two additional simulations with a smaller bulk carrier were run. The pilot's requested these simulations, with flood tide, to experiment with meeting smaller ships in the extension channel. The ship track and parameter plots for these simulations are presented in Plates 73-76. The inbound ship shown in Plate 73 left the north side of the channel by 10 ft prior to and during the meeting situation. The inbound ship was pushed to the channel's north side and the outbound ship to the middle of the channel by the flood currents. The other run (Plate 75) was successfull. However, the inbound ship came within 24 ft of the northern channel edge.

Tolchester Channel

Individual ship track and parameter plots of all runs conducted in the Tolchester Channel are presented in Plates 77 - 208. The distance along track reference line is shown for the existing channels in Figures 6 and for the proposed channel in Figure 7. Average clearance values at time of meeting are presented in Table 3 - 6.

Many of the tests conducted in proposed Tolchester Channel re-alignment show the outbound ship leaving the east side of the channel near the Tolchester Marina, for no apparent reason. This was not noticed until the test program was nearly complete. When questioned about this, the pilots stated that they were trying to stay as far away from the inbound ship as possible by allowing their ship to cross over into the "old" channel. The pilots also said that they could have remained within the authorized channel and met the other ship. Full examination of the results substantiates this. Therefore, the fact that many of the outbound runs left the proposed channel near the marina does not indicate a navigation problem with the re-aligned channel.

Existing Conditions, Ebb Tide, No Ice, Meet in S-Turn

The ship track and parameter plots for ships transiting the existing Tolchester Channel with ebb tide, no ice and meeting in the S-turn are presented in Plates 77 - 86. One or both of the ships left the channel (or came very close to leaving the channel) in all runs. Two of the inbound ships (Plates 79 and 81) left the channel and one ship (Plate 77) came with 17 ft of the channel edge on the west side of the channel across from the Tolchester Marina prior to meeting the outbound ship. Two of the outbound ships (Plates 81 and 83) left the channel and two others (Plates 79 and 85) came within 23 and 7 ft, respectively, of the channel edge. The average clearance values were 321.4 ft between the ships, 189.0 ft from the inbound ship to the channel edge, and 61.0 ft from the outbound ship to the channel edge.

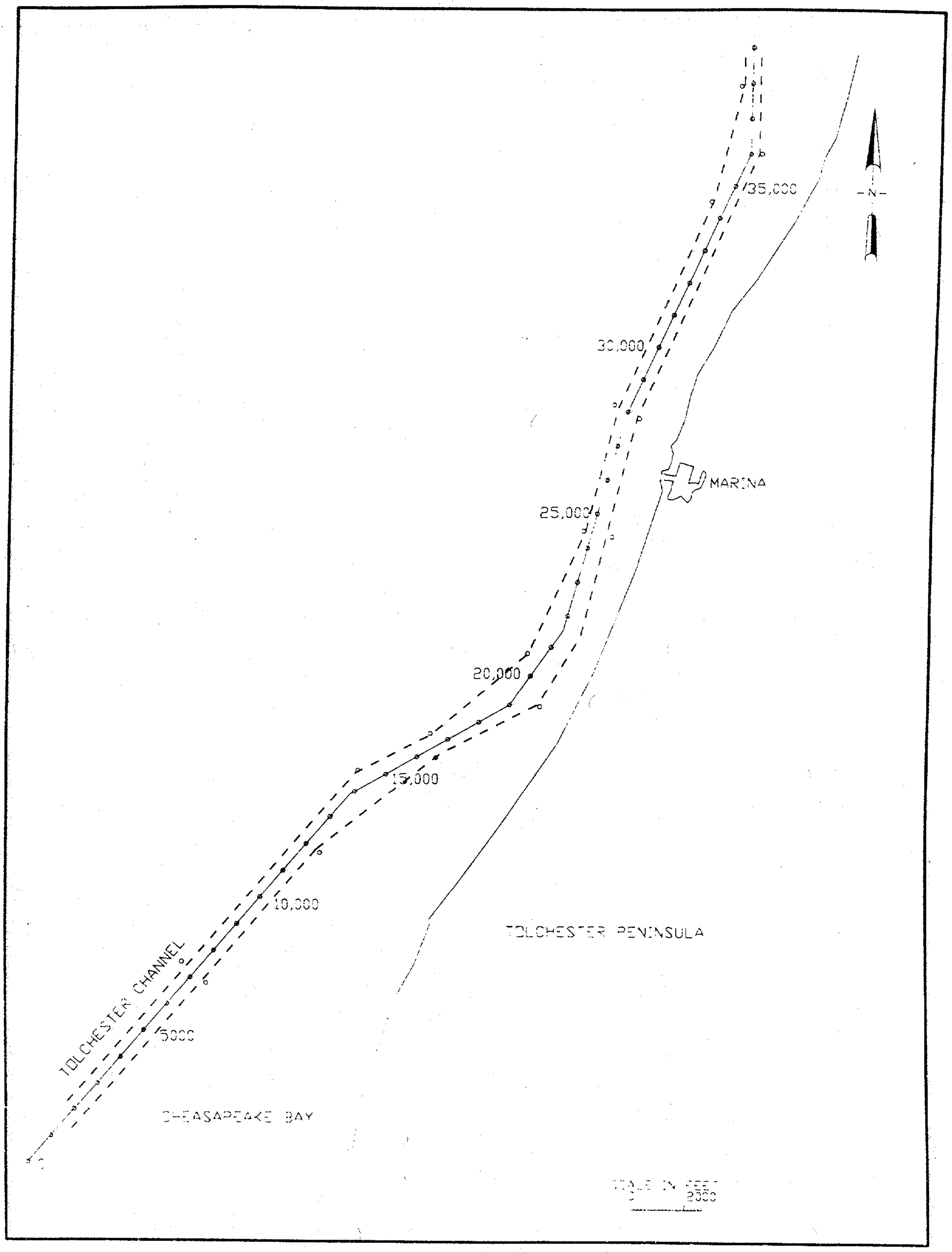


FIGURE 6 Distance Along Track, Existing Tolchester Channel

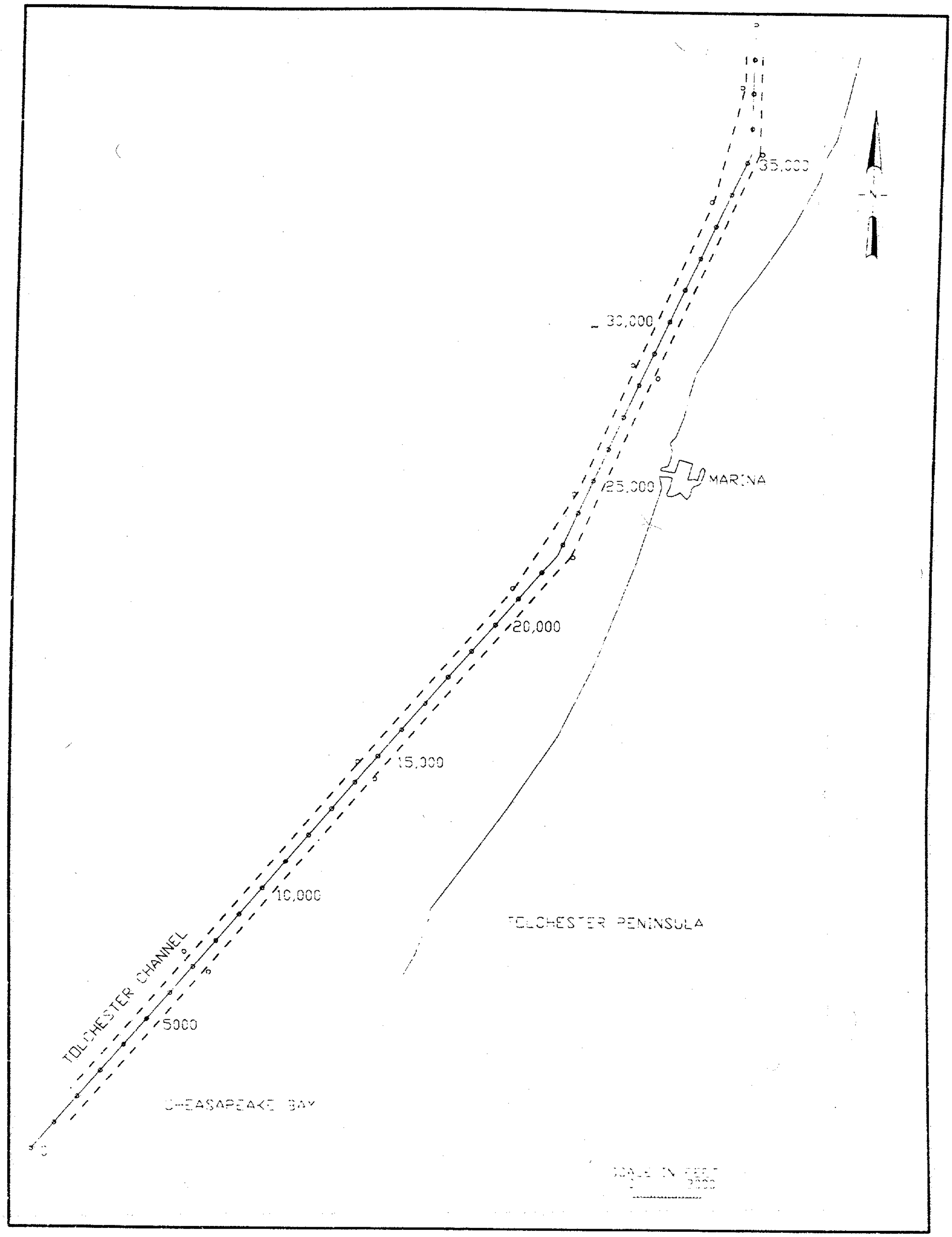


FIGURE 7 Distance Along Track, Proposed Tolchester Channel.

Existing Conditions, Ebb Tide, No Ice, Meet in Straight Segment

The ship track and parameter plots for ships transiting the existing Tolchester Channel with ebb tide, no ice and meeting in the straight section south of the "S-turn" are presented in Plates 87-94. One or both of the ships left the channel in all runs. One of the inbound ships (Plate 89) left the west side of the channel, just north of the marina, well in advance of the meeting situation. One inbound ship (Plate 93) left the channel prior to meeting the outbound ship. One outbound ship (Plate 87) left the west side (inbound side) of the channel prior to meeting the inbound ship. One of the outbound ships (Plate 91) left during the meeting and another (Plate 93) came within 27 ft of the channel edge. The average clearance values were 251.5 ft between the ships, 57.0 ft from the inbound ship to the channel edge, and 45.3 ft from the outbound ship to the channel edge.

Proposed Conditions, Ebb Tide, No Ice

The ship track and parameter plots for ships transiting the proposed Tolchester Channel with ebb tide and no ice are presented in Plates 95 - 106. One inbound ship (Plate 105) came within 15 ft of the east side of the channel edge while making the turn after meeting the other ship. Two of the outbound runs (Plates 97 and 101) left the east side of the channel near the marina. During three other runs (Plates 95, 99, and 105) the outbound ship came within 29 ft, 1 ft, and 16 ft, respectively, of the eastern channel edge. The average clearance values were 234.7 ft between the ships, 203.2 ft from the inbound ship to the channel edge, and 46.2 ft from the outbound ship to the channel edge.

Existing Conditions, Ebb Tide, Ice, Meet in S-Turn

The ship track and parameter plots for ships transiting the existing Tolchester Channel with ebb tide, ice and meeting in the S-turn are presented in Plates 107 - 114. Three out of the four runs (Plates 107, 109, and 111) conducted for this scenario had an incident of one of the ships leaving the channel. On two of the runs (Plates 107 and 109) the inbound ship left the west side of the channel across from the marina prior to meeting the outbound ship. One outbound ship (Plate 111) left the channel during the meeting. The average clearance values were 279.3 ft between the ships, 225.5 ft from the inbound ship to the channel edge, and 154.0 ft from the outbound ship to the channel edge.

Existing Conditions, Ebb Tide, Ice, Meet in Straight Segment

The ship track and parameter plots for ships transiting the existing Tolchester Channel with ebb tide, ice and meeting in the straight section south of the "S-turn" are presented in Plates 115 - 126. Three of the inbound runs (Plates 115, 117, and 125) left the west side of the channel while making the turn near the marina. This area is north of the "S-turn" and well in advance of the meeting situation. One inbound runs (Plate 119) came within 19 ft to the channel edge at the same locations. All of the outbound runs left or came extremely close to the channel edge, trying to maximize ship clearance while meeting the inbound ship. The average clearance values were 318.0 ft between the ships, 59.3 ft from the inbound ship to the channel edge, and 19.5 ft from the outbound ship to the channel edge.

Proposed Conditions, Ebb Tide, Ice

The ship track and parameter plots for ships transiting the proposed Tolchester Channel with ebb tide and ice are presented in Plates 127 - 138. One outbound run (Plate 135) left the eastern side of the channel south of the marina during the meeting situation. Four other outbound runs (Plates 127, 129, 131, and 137) came very close to the eastern channel edge near the marina. The average clearance values were 272.7 ft between the ships, 183.8 ft from the inbound ship to the channel edge, and 49.8 ft from the outbound ship to the channel edge.

Existing Conditions, Flood Tide, No Ice, Meet in S-Turn

The ship track and parameter plots for ships transiting the existing Tolchester Channel with flood tide, no ice and meeting in the S-turn are presented in Plates 139 - 150. Four of the inbound ships (Plates 141, 143, 145, and 149) left or came very close the western channel edge while making the turn just north of the marina. This occured in the area of naturally deep water before the meeting situation was to take place. Three of the outbound ships (Plates 141, 147, and 149) left the eastern side of the channel prior to meeting the outbound ship. The average clearance values were 202.3 ft between the ships, 128.8 ft from the inbound ship to the channel, and 84.3 ft from the outbound ship to the channel.

Existing Conditions, Flood Tide, No Ice, Meet in Straight Segment

The ship track and parameter plots for ships transiting the existing Tolchester Channel with flood tide, no ice and meeting in the straight section south of the "S-turn" are presented in Plates 151 - 162. One or both of the ships left the channel in all runs except one (Plate 151). One of the inbound ships (Plate 155) left the channel while making the turn north of the marina, weel in advance of the meeting situation. Two of the inbound ships (Plates 151 and 153,) came close to the eastern channel edge while making the turn across from the marina. One inbound ship (Plate 161) completely left the channel while meeting the outbound ship. Three of the outbound runs (Plates 153, 155 and 159) left the channel at or near the meeting location. Another outbound ship (Plate 151) came within 25 ft of the channel edge during the meeting. The average clearance values were 287.7 ft between the ships, 58.2 ft from the inbound ship to the channel edge, and 42.7 ft from the outbound ship to the channel edge.

Proposed Conditions, Flood Tide, No Ice

The ship track and parameter plots for ships transiting the proposed Tolchester Channel with flood tide and no ice are presented in Plates 163 - 174. One inbound ship (Plate 163) came within 51 ft of the channel edge while meeting the outbound ship. One outbound ship (Plate 169) stayed in the channel near the marina. The remainder of the outbound ships (Plates 163, 165, 167, 171, and 173) all left the eastern side of the channel near the marina. The average clearance values were 320.3 ft between the ships, 128.7 ft from the inbound ship to the channel edge, and 21.7 ft from the outbound ship to the channel edge.

Existing Conditions, Flood Tide, Ice, Meet in S-Turn

The ship track and parameter plots for ships transiting the existing Tolchester Channel with flood tide, ice and meeting in the "S-turn" are presented in Plates 175 - 186. An additional run (Plates 187 and 188) was intended to be a meeting in the straight segment. However, due to the timing starting the runs, they met in the "S-turn". This run in included in this portion of the result analysis. Four of the inbound ships (Plates 177, 179,181 and 187) left the western side of the channel while making the turn just north of the marina. Two other inbound ships (Plates 175 and 185) came within 21 ft and 12 ft of the channel's edge, respectively. Four outbound runs (Plates 177, 179, 181 and 183) left the channel while, or just prior to, meeting the inbound ship. Another outbound run (Plate 175) came within 5 ft of the eastern edge of the channel. The average clearance values were 207.8 ft between the ships, 110.5 ft from the inbound ship to the channel edge, and 47.8 ft from the outbound ship to the channel edge.

Existing Conditions, Flood Tide, Ice, Meet in Straight Segment

The ship track and parameter plots for ships transiting the existing Tolchester Channel with flood tide, ice and meeting in the straight section south of the "S-turn" are presented in Plates 189 - 198. One of the inbound ships (Plate 189) left the channel while making the turn north of the marina, while another (Plate 197) came within 15 ft of the channel edge. One inbound ship (Plate 191) left the channel while making the turn in the "S-turn", just north of the Tolchester Channel's straight reach. Two inbound runs (Plate 193 and 197) left the channel while meeting the outbound ship. Two other inbound runs (Plates 189 and 195) came within 23 and 47 ft of the channel edge, respectively, while meeting the other ship. Two outbound ships (Plates 191 and 195) left the channel while meeting the inbound ship and two other outbound vessels (Plates 189 and 193) came within 26 ft and 40 ft of the channel edge, respectively. The average clearance values were 319.0 ft between the ships, 89.8 ft from the inbound ship to the channel, and 76.5 ft from the outbound ship to the channel.

Proposed Conditions, Flood Tide, Ice

The ship track and parameter plots for ships transiting the proposed Tolchester Channel with flood tide and ice are presented in Plates 199 - 208. Four of the inbound runs (Plates 199, 201, 205, and 207) came close to the western channel limit while meeting the outbound ship. Four outbound ships (201, 203, 205, and 207) left the eastern side of the channel near the marina. The remaining outbound ship came within 19 ft of the channel edge near the marina. The average clearance values were 300.0 ft between the ships, 68.4 ft from the inbound ship to the channel edge, and 7.6 ft from the outbound ship to the channel edge.

Table 1
Clearances, Brewerton Channel Eastern Extension, Ebb Tide

Plates	Inbound Pilot	Outbound Pilot	Clearance at Time of Meeting, ft				
			Between Ships	Inbound Ship to Channel	Outbound Ship to Channel		
Existing Conditions							
1	1	2	44	65	52		
3	2	1	157	43	18		
5	3	4	80	76	0		
7	4	3	86	62	11		
9	5	6	71	-52	-73		
11	6	5	109	-21	55		
		Average	91.2	49.7	22.7		
Proposed 550-ft Wide Channel							
13	1	2	114	50	70		
15	2	1	129	144	43		
17	3	4	126	61	39		
19	4	3	183	-19	76		
21	5	6	38	182	50		
23	6	5	161	105	56		
		Average	125.2	90.3	55.7		
Proposed 600-ft Wide Channel							
25	1	2	177	43	86		
27	2	1	107	144	22		
29	3	4	100	119	49		
31	4	3	211	25	70		
33	5	6	79	193	79		
35	6	5	185	6	82		
		Average	143.2	88.3	64.7		

Table 2
Clearances, Brewerton Extension Channel, Flood Tide

Plates	Inbound Pilot	Outbound Pilot	Clearance at Time of Meeting, ft: Between Ships	Inbound Ship to Channel	Outbound Ship to Channel
Existing Conditions					
37	1	2	122	-29	85
39	2	1	67	8	26
41	3	4	148	32	37
43	4	3	110	-32	91
45	5	6	115	29	22
47	6	5	135	-75	105
		Average	116.2	11.5	61.0
Proposed 550-ft Channel					
49	1	2	123	32	151
51	2	1	138	42	67
53	3	4	243	64	16
55	4	3	85	60	134
57	5	6	182	49	60
59	6	5	95	34	134
		Average	144.3	46.8	93.7
Proposed 600-ft Channel					
61	1	2	108	39	173
63	2	1	189	111	14
65	3	4	224	117	12
67	4	3	47	106	122
69	5	6	110	52	146
71	6	5	124	-23	169
		Average	133.7	70.8	106.0

Table 3
Clearances, Tolchester Channel, Ebb Tide, No Ice

Plates	Inbound Pilot	Outbound Pilot	Clearance at Time of Meeting, ft: Between Ships	Inbound Ship to Channel	Outbound Ship to Channel
Existing Conditions, Meeting in S-Turn					
77	1	2	323	188	163
79	2	1	178	104	61
81	4	3	319	239	-40
83	5	6	579	226	-5
85	6	5	208	188	81
		Average	321.4	189.0	61.0
Existing Conditions, Meeting in Straight Reach					
87	1	2	225	45	42
89	2	1	186	73	96
91	5	6	262	106	3
93	6	5	333	4	40
		Average	251.5	57.0	45.3
Proposed Conditions					
95	1	2	245	170	81
97	2	1	173	298	21
99	3	4	221	189	42
101	4	3	303	164	32
103	5	6	229	215	75
105	6	5	237	183	26
		Average	234.7	203.2	46.2

Table 4
Clearances, Tolchester Channel, Ebb Tide, Ice

Plates	Inbound Pilot	Outbound Pilot	Clearance at Time of Meeting, ft		
			Between Ships	Inbound Ship to Channel	Outbound Ship to Channel
Existing Conditions, Meeting in S-Turn					
107	1	2	239	193	289
109	2	1	271	270	141
111	5	6	394	219	-57
113	6	5	213	220	186
		Average	279.3	225.5	154.0
Existing Conditions, Meeting in Straight Reach					
115	1	2	316	24	19
117	2	1	198	98	35
119	3	4	240	119	9
121	4	3	432	-45	-32
123	5	6	281	115	-74
125	6	5	441	-102	54
		Average	318.0	59.3	19.5
Proposed Conditions					
127	1	2	296	217	43
129	2	1	248	83	49
131	3	4	255	291	10
133	4	3	324	76	110
135	5	6	336	195	-83
137	6	5	177	241	87
		Average	272.7	183.8	49.8

Table 5
Clearances, Tolchester Channel, Flood Tide, No Ice

Plates	Inbound Pilot	Outbound Pilot	Clearance at Time of Meeting, ft: Between Ships	Inbound Ship to Channel	Outbound Ship to Channel
Existing Conditions, Meeting in S-Turn					
139	1	2	394	209	159
141	2	1	213	127	-9
143	3	4	145	204	101
145	4	3	188	59	102
147	5	6	150	134	53
149	6	5	124	40	91
		Average	202.3	128.8	84.3
Existing Conditions, Meeting in Straight Reach					
151	1	2	241	80	36
153	2	1	295	84	-24
155	3	4	256	107	-11
157	4	3	292	-21	69
159	5	6	277	78	26
161	6	5	365	-162	125
		Average	287.7	58.2	42.7
Proposed Conditions					
163	1	2	417	72	-136
165	2	1	403	95	-148
167	3	4	372	127	-125
169	4	3	210	190	130
171	5	6	250	104	-5
173	6	5	270	184	-79
		Average	320.3	128.7	21.7

Table 6
Clearances, Tolchester Channel, Flood Tide, Ice

Plates	Inbound Pilot	Outbound Pilot	Clearance at Time of Meeting, ft Between Ships	 Inbound Ship to Channel	 Outbound Ship to Channel
Existing Conditions, Meeting in S-Turn					
175	1	2	268	152	46
177	2	1	222	107	-10
179	3	4	255	104	6
181	4	3	199	61	93
183	5	6	141	141	47
185	6	5	162	98	95
187[1]	1	2	388	171	247
		Average	233.6	119.1	76.3
Existing Conditions, Meeting in Straight Reach					
189	2	1	237	51	40
191	3	4	288	137	-60
193	4	3	295	7	76
195	5	6	309	70	-5
197	6	5	397	103	96
		Average	305.2	73.6	42.4
Proposed Conditions					
199	1	2	255	71	30
201	2	1	321	39	6
203	3	4	231	127	2
205	4	3	421	22	-121
207	6	5	272	83	-27
		Average	300.0	68.4	7 6

[1] Due to the starting times for the inbound and outbound ships, the meeting occured in the "S-Turn", rather than in the straight reach, as originally planned.

Pilot Questioniarres

Brewerton / Tolchester Navigation Study
Pilot Debriefing Form

The following questions address the realism of the simulation transits and the specific channel design changes that have been proposed. Also attached are figures of the project site. Your responses will be included in the WES report, anonymously.

1. How long have you been a Maryland Pilot?

1) 20 Years
2) 17 Years
3) 25 Years
4) 25 Years
5) 25 Years
6) 20 Years

About how many times have you piloted a ship in the Brewerton Extension and Tolchester Channels?

1) 600 times
2) 30 to 35 per year or approximately 560 ships.
3) Approximately 650 times.
4) 700 times
5) 625 times
6) 500 times approximated

About how many of these transits have been in a ship similar in size to the ship used in this study? (956- 106- 33-ft Containership)

1) 25
2) 20 ships
3) 20-25
4) 10
5) 25 times
6) I guess none. 33 ft draft. 956 about 10%; 106 ft 25%.

2. Did the simulated ship handle as expected?

1) For speed up 80%. the simulated ship handled very realistically. However. when turning speeds over 80%. the simulated ship handled too well and predictable. On the simulator. I reached speeds of 14.5 knots and required only minimum rudder angle to maintain control. while in a real situation we would be almost impossible to control at that speed in the existing channels.

2) Your simulator is the third one I have used and it is by far the best simulator in most closely approximating the actions of a ship in a confined channel.

3) In general I would say the overall effect was realistic. This was the most realistic simulation. in terms of ship behavior, that I have worked with to date. The fault I noted was that the ship had a bit to much longitudinal stability; that is. when you put the rudder midships she steadied up to quickly. Overall she probably handled better than a typical ship of her size.

4) Somewhat. It did not continue swinging as much as a real ship when trying to steady.

5) Generally. the simulation was accurate. The effects experienced with respect to the banks was real. The ship-to-ship interaction was a bit exaggerated although we seldom have 900+ ships meeting each other so perhaps the effects were close.

6) When left along it came off the banks like a real one but it did not respond in a real way to increased revolutions. i.e. better steerability at lower speed. \The ship was uncontrollable at slow speed. this does not occur in practice.

3. Did the environment effect your ship as expected?

Wind?

1) Yes. although set by wind seemed to be more severe in the simulator than my experience would lead me to expect.

2) Wind effect was less than expected.

3) It is difficult to differentiate accurately between wind and current effects. but on those occasions where the wind was strong and blowing on the beam it was possible to note the effects on the ship. I would like to have repeated certain runs with no wind immediately after a run with strong wind. just to note the differences.

4) Yes

5) Did not notice the wind as other effects.

6) I suppose so.

Ebb tide?

1) Yes

2) Very good simulation

3) The effect of the tidal currents were clearly evident and effected the movement of the ship considerably.

4) Yes

5) I thought the ebb and flood tide effects were very accurate.

6) This effect seemed to great

Flood tide?

1) Yes

2) Very good

3) The effect of the tidal currents were clearly evident and effected the movement of the ship
considerably.

4) Yes

5) Same as above.

6) Less than ebb.

Ice?

1) Yes, while ice offers resistance and affects speed, it also provides a cushion which enhances control most times. However, sometimes the ship finds a soft spot in ice and sheers into it unexpectedly.

2) Good

3) The ice effects clearly slowed down the speed and the rate of turn of the ship. The appearance of the ice was not as realistic looking as that of the open water.

4) Somewhat.

5) The ice was also simulated well - including slowing of vessel and difficulty in seeing buoys readily.

6) No. It only seemed to reduce speed.

3a. Were the bank effects realistic?

3) Bank effects. I found the bank effects to be reasonably accurate, however, I feel that a major flaw in the simulation was that the ship could never "run aground." There were several times that I ran the ship on the channel edge and probably should have grounded. This effect really should be added to the simulation.

4) No. A real ship would not have been able to get as close to the channel edge without losing control.

5) Bank effects were very accurate as previously stated. The phenomena of "Holding rubber" as vessel nears a bank was especially evident. Vessels of 33' draft would probably not be able to get over as far as they did in simulation.

6) Yes.

4. Was the ship to ship interaction as expected?

1) Ship to ship interaction was fairly realistic. The two ships in our study usually slowed down prior to meeting and relied on increasing engine power when abreast. This usually will break or minimize a sheer after passing in a real situation, but the simulator was sluggish executing this maneuver.

2) The performance of the ship to ship interaction was excellent.

3) Ship interaction. This was realistic, but, I believe, somewhat late in occurring. The ship seemed to "feel" the interaction past the point that I would have expected it to occur, based on my experience with the real thing. The "dive" which my ship took toward the passing ship, for example, should have occurred while the stern of the passing ship was still abreast of, roughly, my midship point, ratter than well after the two ship's sterns were clear of one another.

4) Yes, but ship interaction exaggerated.

5) Ship to ship interaction was a bit unrealistic. As mentioned to Dennis Webb, when pilots have meeting ships' bows a-beam normally a port rudder order is given to swing sterns away, but in simulation this practice nearly caused collisions.

6) No. I think the forces were to extreme. I"ve never had a collision with a real ship and I had too many with the simulated one. You figure.

5. On a scale of 1 to 10, with 10 being the best, please rate the realism of the simulation model?

1) 8.5

2) 8.5

3) I rated the realism of the ship movement at about 9, but the visual appearance at a 7.

4) 8.5

5) I have been through 3 other simulators and I rate the WES simulator an 8.5, by far the most realistic.

6) 4 however it's the best simulator I've seen (compared to 2 others.)

6. Was the proposed 550-ft Brewerton Extension channel wide enough to safely meet the two 965- x 106- x 35-ft containerships?

1) Under most circumstances the 550' channel would be adequate for two 965' ships to meet. Of course, prudent ship handling involving moderate speeds and skillful anticipation would be required to maximize safely.

2) Would be ok under most weather conditions.

3) Based on our experience on the simulator I would rate the 550' channel as unacceptable for the meeting of two 965x106 containerships.

4) No - It can usually be done but not enough room for error or normal shipboard malfunctions.

5) Although I personally would still avoid meeting two vessels of this size in the extension, the widening to 550' would greatly improve the situation.

6) Based on answers 1-6 I have to say that to answer 7, 8, 9 good, better, best respectively, you must consider that the simulations parameters got increasingly more favorable as the channels get bigger.

7. Was the proposed 600-ft Brewerton Extension channel wide enough to safely meet the two 965- x 106- x 35-ft containerships?

1) The 600' channel provided a larger measure of safety for two 965' ships to meet.

2) Yes

3) Yes, Since this is the widest possible channel dimension being considered. I would opt to go with 600'. My simulator experience dictates this as the only acceptable width for the meeting of this class of ship.

8. Do you foresee any situations for which either the 550- or 600-ft Brewerton Extension Channel would be inadequate.

1) During periods of reduced visibility and strong cross channel currents, two large ships may gave a risky meeting. However during situations such as this arrangements could be made to avoid meeting in that cut. (Slow sown to allow other ship to exit, or use Swan Point Channel to the South)

2) No

3) In the scenario involving the requirement to kill time in the Brewerton, i.e., run at slow speed with a strong cross current, neither of these channels might be wide enough to transit safely and especially not for meeting other ships.

4) No, except when two large ships meet.

5) If two vessels of this size were forced to meet in the extension, the only condition to avoid would be heavy ice with buoys missing or reduced visibility.

6) No. Bigger channels are always more adequate than smaller ones.

9. What was the most complicated aspect of this Brewerton Extension Channel scenario?

1) Inbound ship during ebb tide and north wind made for difficulty in maintaining my side of the channel.

2) Meeting with the ebb tide and north wind.

3) The most complicated aspect involved meeting another ship in the 450' channel. I don't believe I did it once to my satisfaction. No matter what the current or wind, we were never able to find the right combination of speed and closeness to the bank in order to meet and pass successfully with the existing channel width.

4) Ship interaction causing swinging.

5) Meeting 2 large ships in turns.

6) My track record shows entering and exiting that I had trouble.

10. Would you have preferred not to use the Brewerton Extension? Explain.

1) With existing channel, I would definitely NOT meet in that channel with these two ships. If the channels were 600' wide, only experience would determine if I would plan a meeting of two 965', 33' draft ships there

2) No

3) My experience on the simulator supports the concept of avoiding the meeting of another large ship in the Extension Channel, as we currently do in real life. I had no problem making the turn east or westbound in the Extension, no matter what the length and beam of the two ships. I would also consult with the other pilot regarding the handling of his ship and get his opinion on the safety of having the two ships meet in the Extension.

4) Yes crosscurrent makes meeting more difficult with large deep ships.

5) There have been instances when prudence would dictate to "Go Around" and avoid the extension, especially if the vessel had the time to spare and it could avoid a potential close quarter situation.

6) If I though I would have those same problems with a real ship under existing or improved conditions I would.

What would be the deciding factor(s)?

1) Strength of current. Visibility. Observed competence of crew (helmsman). Agreement with pilot I am meeting.

2) I would not meet in the extension in fog.

3) In meeting another ship, the deciding factors would be weather conditions, the size and draft of the two vessels and haw well my ship is handling. Draft in particular is important. I would currently never meet another 33' draft ship in the Extension, no matter what the length and beam of the two ships. I would also consult with the other pilot regarding the handling of his ship and get his opinion on the safety of having the two ships meet in the Extension.

4) current, weather, traffic

5) Deciding factors would be size and draft of vessel to meet, weather conditions, ship handling of my vessel, and "comfort factor" of myself and fellow pilots on opposing vessel.

6) Ebb tide strength.

Did you have enough room to maneuver properly? Explain.
1) Under most circumstances, I felt I had room to maneuver. The presence of a third vessel or small boat might affect my option.

2) The 600 ft channel allowed the ships to maintain more headway which reduced the rate of set and allowed the ships to meet more comfortably.

3) With the simulated ships meeting in the Extension I did not have enough room to maneuver in either the 450' of the 550' channels. We either collided or (apparently) ran aground just about every time.

4) With smaller ships you do - shallow draft lets you get closer to channel edge.

5) In this simulation I had room to safely meet the opposing vessel.

6) There was more room but I can't say because the ships didn't maneuver realistically enough for me.

Would you act differently next time? Explain.

1) No.

2) No

3) We were never able to find a suitable speed that seemed to make meeting in the Extension a safe evolution. Not enough speed meant to much "crabbing" and our sterns would hit. To much speed meant that we were sucked together alarmingly. Perhaps we might have gotten it right with another day of practice, but this was not the purpose of the exercises.

4) No

5) I felt comfortable with the present actions.

6) No

10a. Describe any problems associated with the existing Tolchester Channel alignment.

3) Tolchester. Generally, we were able to meet and pass safely every time in the existing Tolchester Channel. There were a couple of times that I thought I might have gone to far to the east when outbound, but the printouts will tell me that.

4) In the "S" turn you are constantly changing course. This is difficult in fog, ice, etc.

5) There are several short turns necessary to transit the "S" turn which necessitate many buoys and ship maneuvers. With a basic straight line run, these difficulties would be eliminated and further, if range lights could be installed, the advantage would be further enhanced ice situations would be tremendously eased.

6) I didn't have any problems in this area on the simulator nor do on real ships.

11. Does the proposed Tolchester realignment improve navigation for:

Two-way Traffic?

1) Yes Under all circumstances, the proposed Tolchester channel offers a big improvement.

2) The proposed Tolchester would be a great improvement in ice, fog, and ships meeting.

3) There is no question that a wide, straight channel is safer than one with an "S" turn in it, no matter what the conditions of weather or visibility. Weather or not the expense is warranted for that increased degree of safety is another matter. We have had large ships run aground in this area and in conditions of heavy ice, with no buoys visible, it can be a difficult channel to run. The simulator was not geared to telling us this, however, and with the existing simulation, we had no problems meeting and passing.

4) Very much so.

5) Of course, two vessels on straight line courses is obviously more desirable than zig-zagging through turns.

6) Yes

Ice Conditions?

3)Yes

4) Very much so

5) Yes, Especially if range lights could be added.

6) Yes

Night, Fog, or other limited visibility situations?

3)Yes

4) Very much so

5) Yes, in restricted visibility it is always more desirable to be on straight line courses rather than turning on buoys for short runs as are present in the "S" turn.

6) Yes

Any other problems described in your answer to question 11?

4) No

5) None

12. Any other comments regarding the simulation or proposed channel modifications?

1) Simulation: Very good set up. The only thing that was less than realistic was suction and cushion at high power. Was good at medium power but should have been a little more pronounced at full power.

3) I think it would have been interesting to be able to look at the printouts of the vessel tracks after we ran them. I would know, for example, if I had been running to close to the edge of the channel on previous runs. This would allow me to position the ship differently on future runs for a more accurate simulation. I

would also like to see: A nighttime simulation; a foremast on the tanker simulation; more realistic looking ice.

4) I am very much in favor of the Tolchester realignment. It will make piloting much safer.

5) My opinion is if there is any priority given to

1. Widening of Brewerton extension on

2. Realignment of Tolchester channel, I would prefer to have the Tolchester channel alignment first. The extension can be circumvented in extreme situation by A) Going around Swan Pt. B) waiting for one vessel to pass and clear before the vessel enters. The Tolchester channel is much more urgent and from a layman's point of view, seemingly not that difficult to execute.

6) I have not noticed shoaling in the Tolchester area. Will new channels be more subject to schoaling than the maintained natural channel?

The following questions concern "real life" navigation in the Brewerton Extension Channel, not the simulation study.

13. What percentage of your transits through the C&D Canal do not use the Brewerton Extension?

1) Eastbound - 1%, Westbound 1%

2) Eastbound - Less than 5%, Westbound less than 5%

3) At the present time I would expect to use the Brewerton Extension every time on passages between Baltimore and the C & D Canal. I currently use the Swan Point Channel only when piloting ships bound up or down the Bay and not calling at Baltimore. This amounts to perhaps less than 5 percent of all the Canal Transits.

Only the most unusual circumstances would dictate that I not use the Extension on a trip between Baltimore and the Canal.

An example of an unusual circumstance would be the last minute discovery of a very deep draft vessel about to enter the Extension from the opposite end. Normally, two deep ship's pilots would know each other was coming and adjust their speeds to avoid meeting in the extension.

Another unusual circumstance would be a vessel broken down and blocking the channel or a dredge blocking the channel.

No other conditions that I could think of would make me decide not to use the Extension.

Since my circumstances for electing not to use the Extension would only be unusual ones as mentioned above, there can be no real "solutions" to the problems. A wider channel (600') would make it less likely that a channel blockage would occur.

4) 0.2% Eastbound, 0.2% Westbound

5) 0% Eastbound, 2% Westbound

6) 2-3% Eastbound, 2-5% Westbound

14. Consider the following list.
What circumstances are most influential in deciding not to traverse the Brewerton Extension? Choose up to the three.

Pilot 3

RANK EXPLAIN

Vessel LOA
Vessel beam
Vessel draft 1
Rather than not use the channel, I make arrangements Vessel class
For one of the vessels to slow to allow other to exit. Direction
Weather
Currents
Fog
Ice
Wind
Other vessels 2 Same reason as above.
Channel conditions
ATONS
other 3 Need to adjust arrival in Baltimore and weather makes it unsafe to traverse channel at slow speed.

Pilot 4

RANK EXPLAIN

Vessel LOA
Vessel beam
Vessel draft
Vessel class
Direction
Weather
Currents
Fog 2 Combined with the tug traffic I could go down and around Swan Pt. Channel
Ice 3 If ranges are nor visible the ice buoys can not be trusted
Wind

Other Vessels 1 To avoid meeting in Brewerton Ext.

Channel Conditions

Atons

Other

Pilot 5

RANK EXPLAIN

Vessel LOA 10 No factor
Vessel beam 9

Vessel draft 6
Vessel class 11

Direction 12
Weather 3 Thunderstorm
Currents 5 Leeway
Fog 2 You have to allow so much leeway
Ice 8 No factor
Wind 4 Leeway
Other Vessels 1 Will wait for other ship to clear
Channel Conditions 7
Atons
Other

Pilot 6

RANK EXPLAIN

Vessel LOA
Vessel beam

Vessel draft 1 Schoaling is a problem - current is on beam
Vessel class
Direction
Weather

Currents
Fog 2 Need to see visually with set and drift so dramatic.
Ice 3 Difficult to navigate when buoys are gone or incorrect.
Wind
Other Vessels
Channel Conditions
Atons
Other

RANK EXPLAIN

Vessel LOA
Vessel beam

Vessel draft 1 Along with traffic is primary
Vessel class

Direction ______ ________________________
____________ Weather ___3___ This may influence decision to go down the bay
Currents ______ ___
____ Fog
_____ ____ Ice
_____ ________________________________
___ Wind ______ __________________________
______________ Other Vessels ___2___ This depends on what the traffic is ________________
Channel Conditions ______ _
____ Atons
_____ ________________________________
Other ______ ________________________________
______

b. Do You have any proposed solutions to these problems? Describe.

5) 1- Vessel Draft - obvious answer is to deepen the channel!

2- Fog - Nothing can be dome about fog except exercise good judgement when deciding to proceed.

3- DGPS is a new aid which will greatly improve our positioning accuracy in ice conditions. This coupied with proper radar use should make the situation much more comfortable.

6) Pilots cooperate with each other with regards to an unofficial vessel traffic control. It has never been a problem for me to get the feel. For the situation by talking with the other pilot. With tugs and federal pilots I am less comfortable with their opinions. I may be less inclined to meet them or hold back behind them. I never overtake.

15. How do you react to an oncoming vessel not yet in the Brewerton Extension if:

- you are eastbound in the Brewerton Extension?

1) Either ask him to slow to allow me to exit first of if both ships are average draft and size agree to meet him in Extension. I like to allow him time to execute turn first and be well in control before I meet Him. (Don't meet close to east end)

2) Ask the ship to hold out till we clear.

3) In any of these cases, the answer is communication. Give a security call before entering the channel to check for approaching vessel. Call the pilot office to check for sailing that might be using the Extension. Watch the radar for any vessel that might not have answered a radio call. Once communications have been established, make a decision based on mutual agreement whether the ships should either meet in the channel or whether one should slow down to wait for the other to clear. Very simple. Works almost every time.

4) Ask him to wait.

5) ask him to wait for me to clear extension.

6) Talk it over on the radar . See 16b for the details.

- you are westbound in the Brewerton Extension?

1) Make arrangements to exit first and then meet or if agreeable, make preparations to be on my side and in control when meeting in channel

2) Ask the ship to hold out till we clear.

4) Ask him to wait.

5) ask him to wait for me to clear.

6) same as above.

- you are eastbound approaching the Brewerton Extension?

1) If neither ship is yet in Brewerton Extension agree on safety of meeting in channel. Determined by weather, draft, ship class. If not considered safe, one will slow down well in advance to allow other to exit.

2) Adjust speed not to meet in extension or go around via Swan Pt. Channel.

4) Wait for other ship to clear.

5) assess situation, discuss with opposing pilot who can safely pass first and who can comfortably kill time.

6) same as above.

- you are westbound approaching the Brewerton Extension?

2) Adjust speed not to meet in extension or go around via Swan Pt. Channel.

4) Wait for other ship to clear.

5) same as above

6) same as above.

16. How is your decision whether to use the Brewerton Extension affected by an oncoming vessel already in the Brewerton Extension if:

- you are approaching the Extension eastbound?

1) If another ship is already in Brewerton Extension Westbound, I would consider slowing down to let him exit first. Since the Brewerton Extension is a 35' channel and joins a 50' channel at North Pt. Westbound ships sometimes experience a dive toward deeper water.

2) If possible I will adjust speed to let ship clear extension.

3) Weather I am eastbound or westbound my decision to enter is always based upon mutual agreement with pilot of the other ship.

4) If a ship, I will wait until he clears.

5) Do I have enough time to kill to avoid meeting in extension? Is my vessel and approaching vessel safe to meet? Concern would be size of vessel draft, beam, length, handling characteristics.

6) I would prefer to meet in the Brewerton channel by holding my ship back.

- you are approaching the Extension westbound?

1) My decision to use Extension westbound with another vessel already in channel is determined by other vessels handling characteristics. General, I don't mind meeting most ships in the extension.

2) I will adjust speed to let vessel clear extension or go around via Swan Pt. Channel

4) If a ship, I will wait until he clears.

5) same as above

6) I prefer to let the other ship clear.

17. To what extent is your decision on whether to use the Brewerton Extension influenced by:

	none	some	much
a. The availability of the berth?	2	3	

b. The vessel's adherence to a schedule? none some much

none	some	much
1	3	1

c. Other timeliness issues? none some much

none	some	much
	3	2

3) Timeless issues are always secondary to safety. If my ship is in a hurry, that would be a factor only if the pilot of the approaching ship is agreeable to slowing down until I clear the channel.

18. Have you changed your operating strategy over the past two years? if so, how and why?

1) No.

2) No

3) My operating strategy has remained unchanged over the last two years. Communications have, if anything, improved during that time, making contact with the approaching vessel easier that it was in the past. A larger percentage of ship's are now piloted by members of the Association, due to a reduction in the number of coastwise vessels. It always seems easier to contact a fellow state pilot who knows the routine than a federal pilot not that familiar with our operating concepts.

4) No

5) Why two years? My operating strategy concerning the extension has always been the same. Nothing has happened in the last 2 years to change this. I believe that good judgement, communication, and cooperation are tantamount in the job of piloting on the canal route.

6) No

In conclusion I would like to express my appreciation to Dennis, Peggy, Moira, and Debbie for their assistance and cooperation during our three days at W.E.S. The experience was a valuable and enjoyable one for me and I would be happy to participate in any such activities in the future. We very much appreciate your efforts on our behalf to improve the safely of the Chesapeake Bay waterways! I

5 Conclusions and Recommendations

Brewerton Channel Eastern Extension

The navigation study shows that the existing 450-foot width and proposed 500-foot width are inadequate for the meeting of two Panamax (965-foot length, 106-foot beam and 33-foot draft) containerships in the Brewerton Channel Eastern Extension. The simulation runs for the proposed 550-foot width resulted in fewer incidents of vessels leaving the channel than simulation of the proposed 600-foot width channel. However, the average bank clearances at the time of meeting for the 550-foot channel are considered low, particularly on the south side of the channel during ebb tides (average bank clearance of 55.7 feet) and on the north side of the channel during flood tides (average bank clearance of 46.8 feet). In addition, the minimal bank clearances recorded for the simulation runs were usually less than those reflected at the time of meeting as a result of the ship to ship interaction during the meeting situation. The higher incidence of vessels leaving the channel during simulation of the proposed 600-foot channel cannot be explained except that the pilots may have been less attentive given the wider channel in which to navigate. Simulation of the proposed 600-foot width resulted in higher bank and ship clearances than the proposed 550-foot width channel and is, therefore, recommended as the safer alternative.

Tolchester Channel

The proposed Tolchester Channel re-alignment significantly reduced the number of groundings when the two ships meet and for inbound ships making the turn just north of the marina. The only discrepancy in the results is outbound ships leaving the east side of the channel near the marina. However, as previously stated, this is a result of the pilots taking advantage of the naturally deep water in the area. Attempting to maximize the distance between themselves and the inbound ship, the pilots crossed the channel boundary. Examination of runs that did not leave the channel and the plots of rudder and engine speed for those runs that did leave the channel indicate that there would be no reason for the pilots not to stay within the authorized channel.

6 References

Teeter (in prep)

V. Ankudinov (1988). "Hydrodynamic and Mathematical Models for Ship Maneuvering Simulation of the Bulk Carrier Asian Banner in Deep and Shallow Waters, and Bank Effects Module in Support of WES Sacramento Channel Study," Technical Report 87005.02-1, Prepared under Contract No. DACW39-87-D-0029 by TRACOR HYDRONAUTICS, Inc, Laurel, MD, for US Army Engineer Waterways Experiment Station, Vicksburg, MS.

V. Ankudinov (1995a). "The Computer Model for Ship Maneuvering Simulations of an Evergreen R-class Containership in Support of WES Charleston Harbor Navigation Study,' Prepared Under Contract No. DACW-39-91-D-0006 by Designers and Planners, Inc., Arlington, VA, for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

V. Ankudinov (1995b). "The Ice Effects Computer Model for Ship Maneuvering Simulations on the WES Ship/Tow Simulator in Support of WES Brewerton/Tolchester Navigation Study,' Prepared Under Contract No. DACW-39-91-D-0006 by Designers and Planners, Inc., Arlington, VA, for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

PRELIMINARY

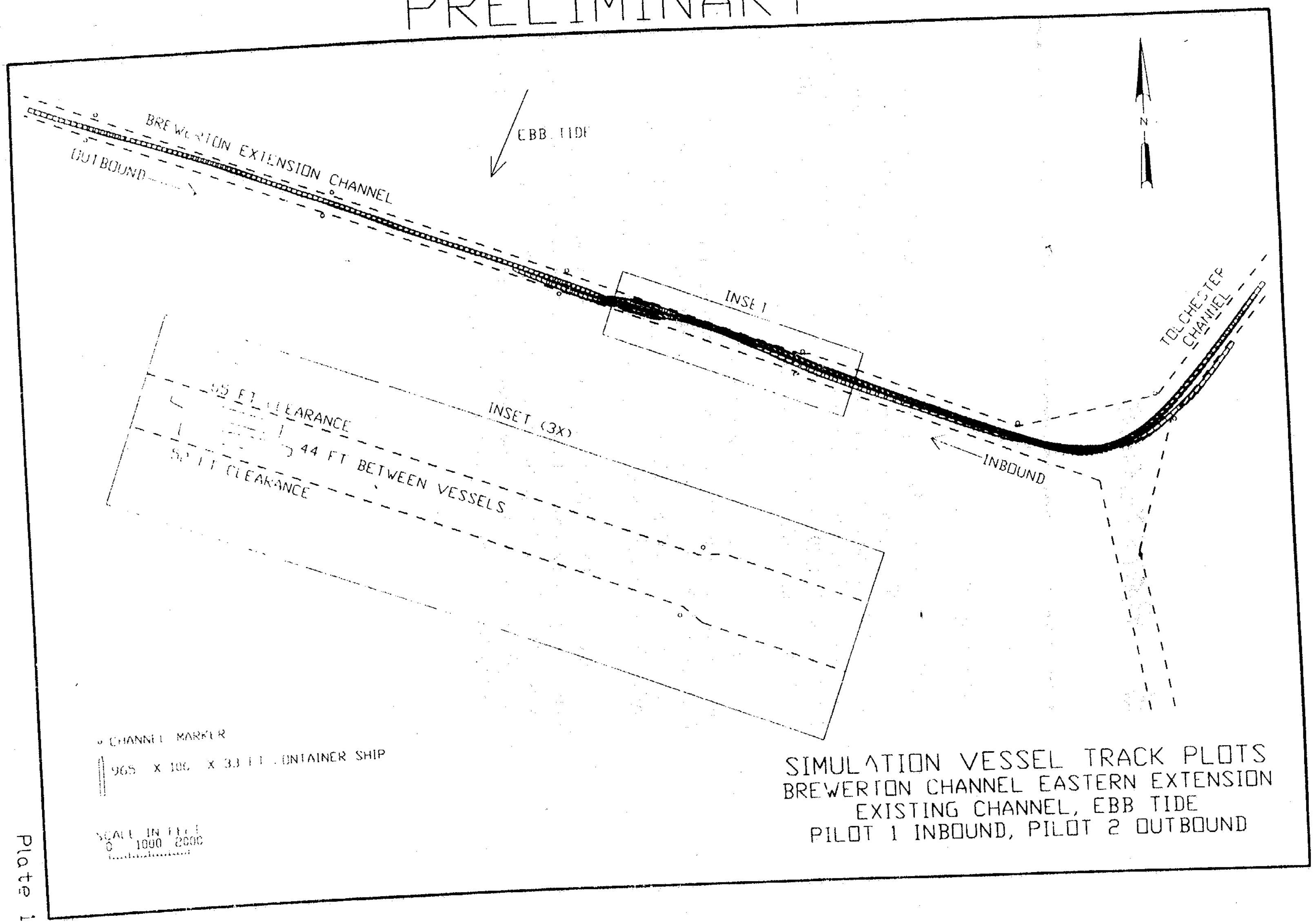
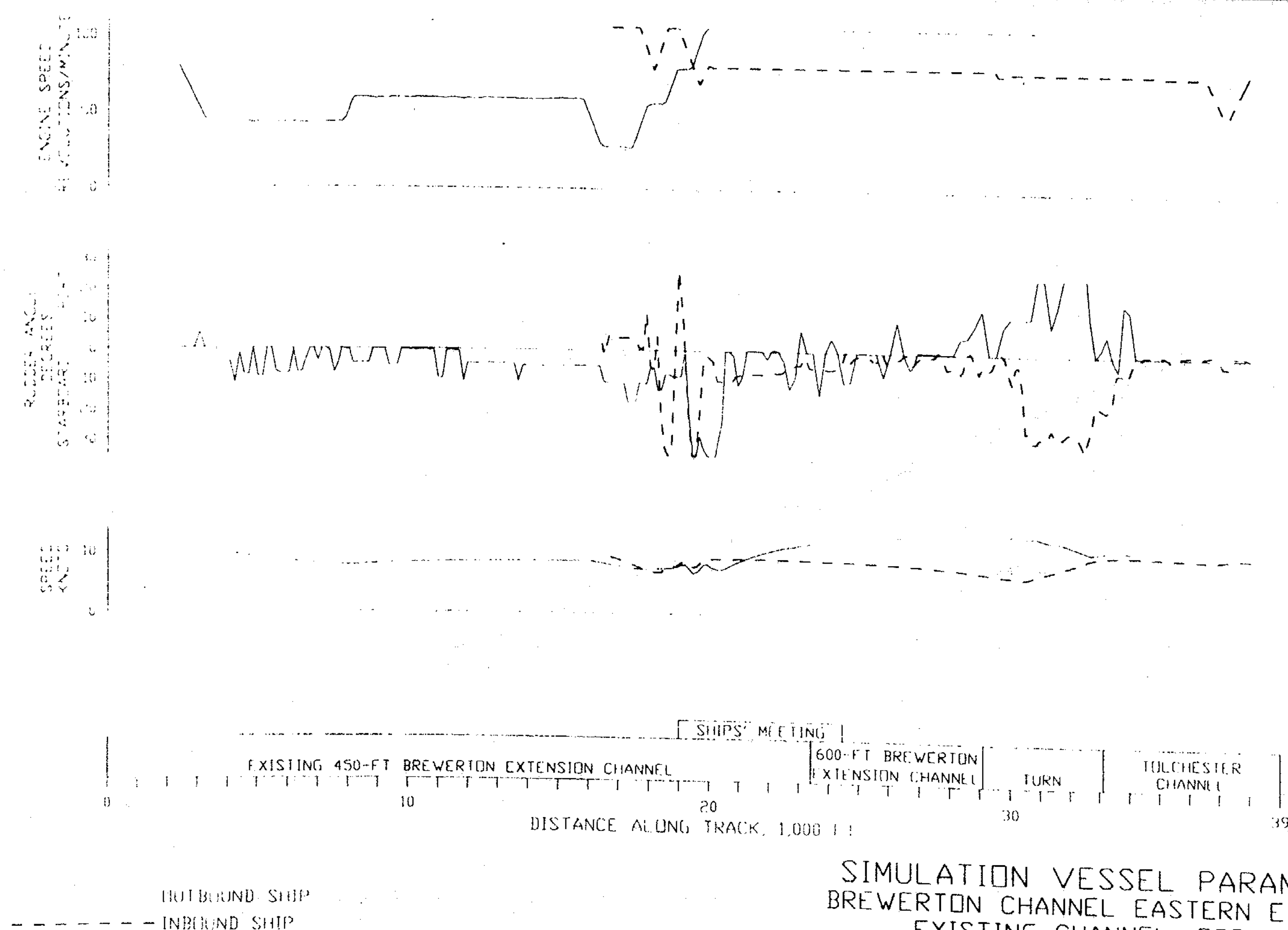


Plate 1

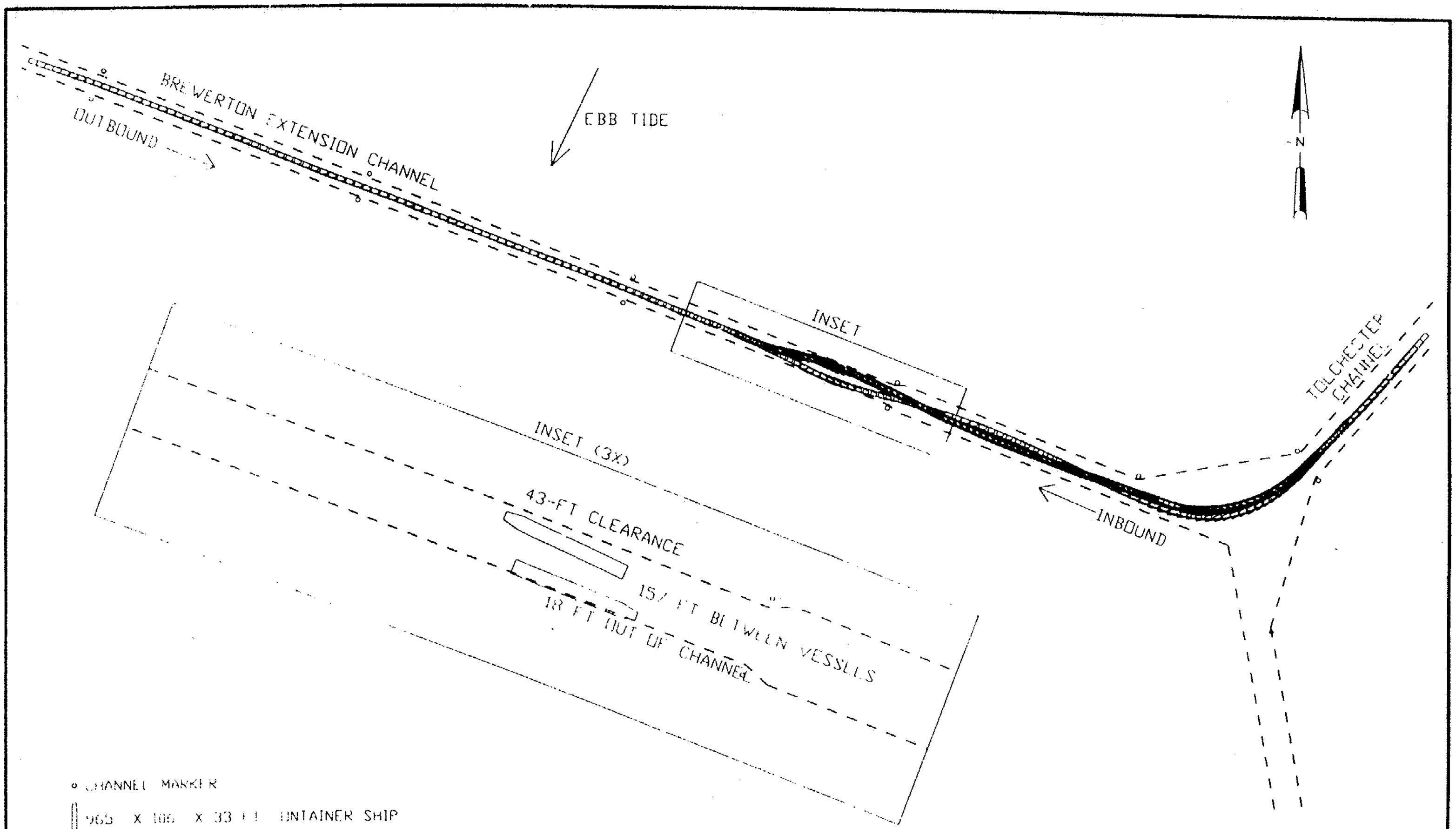
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 2

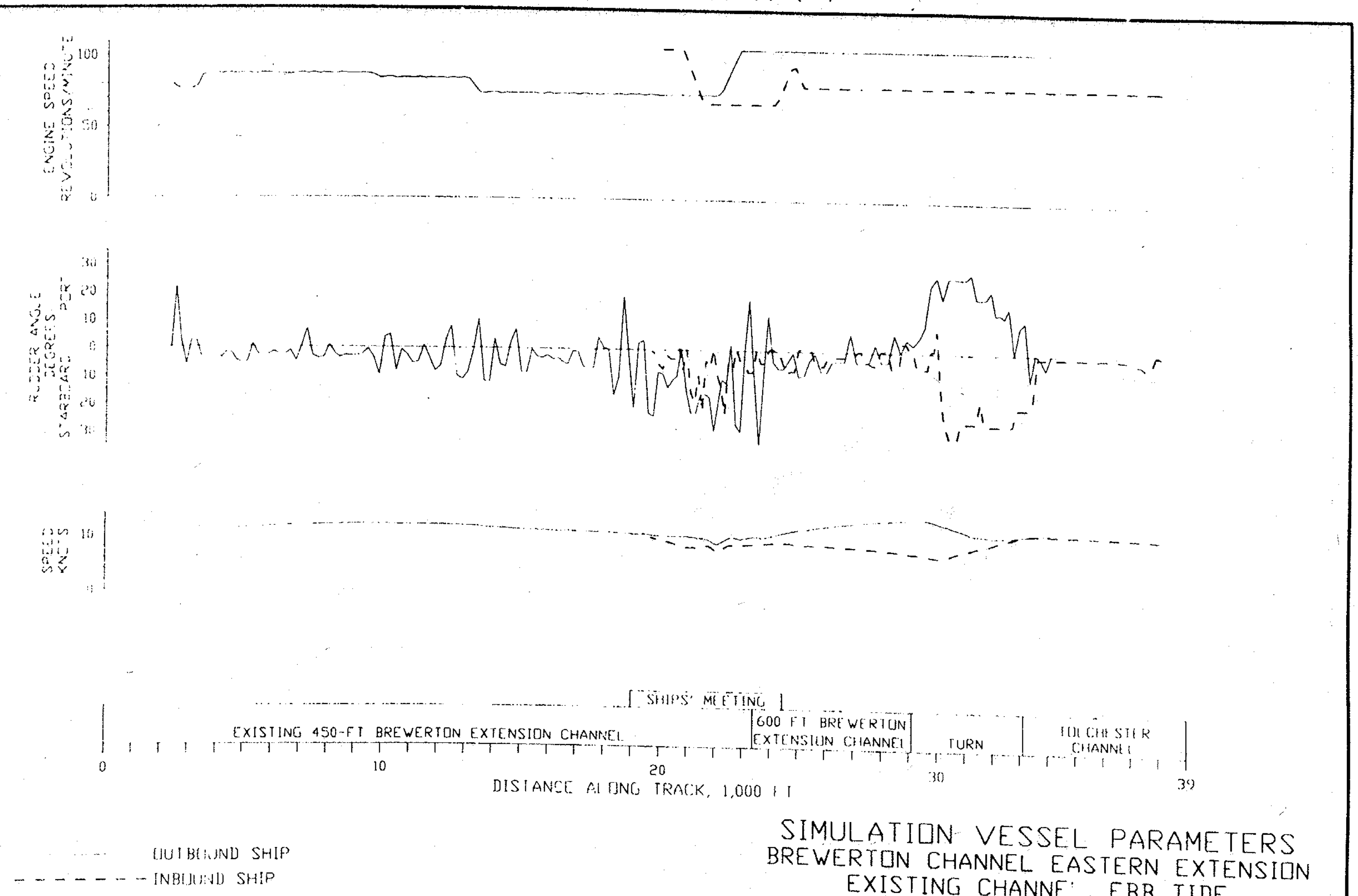
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 3

PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 4

PRELIMINARY

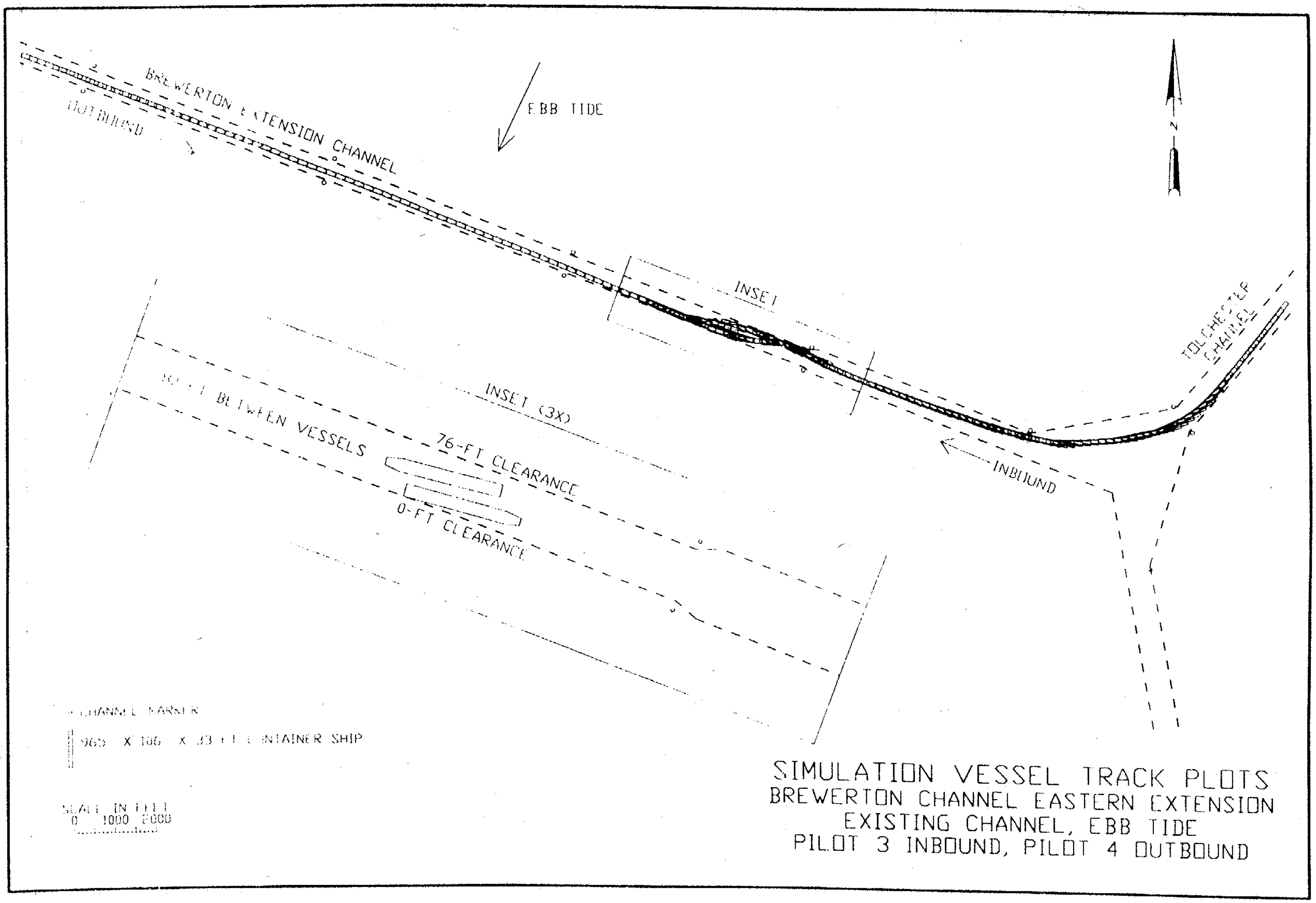
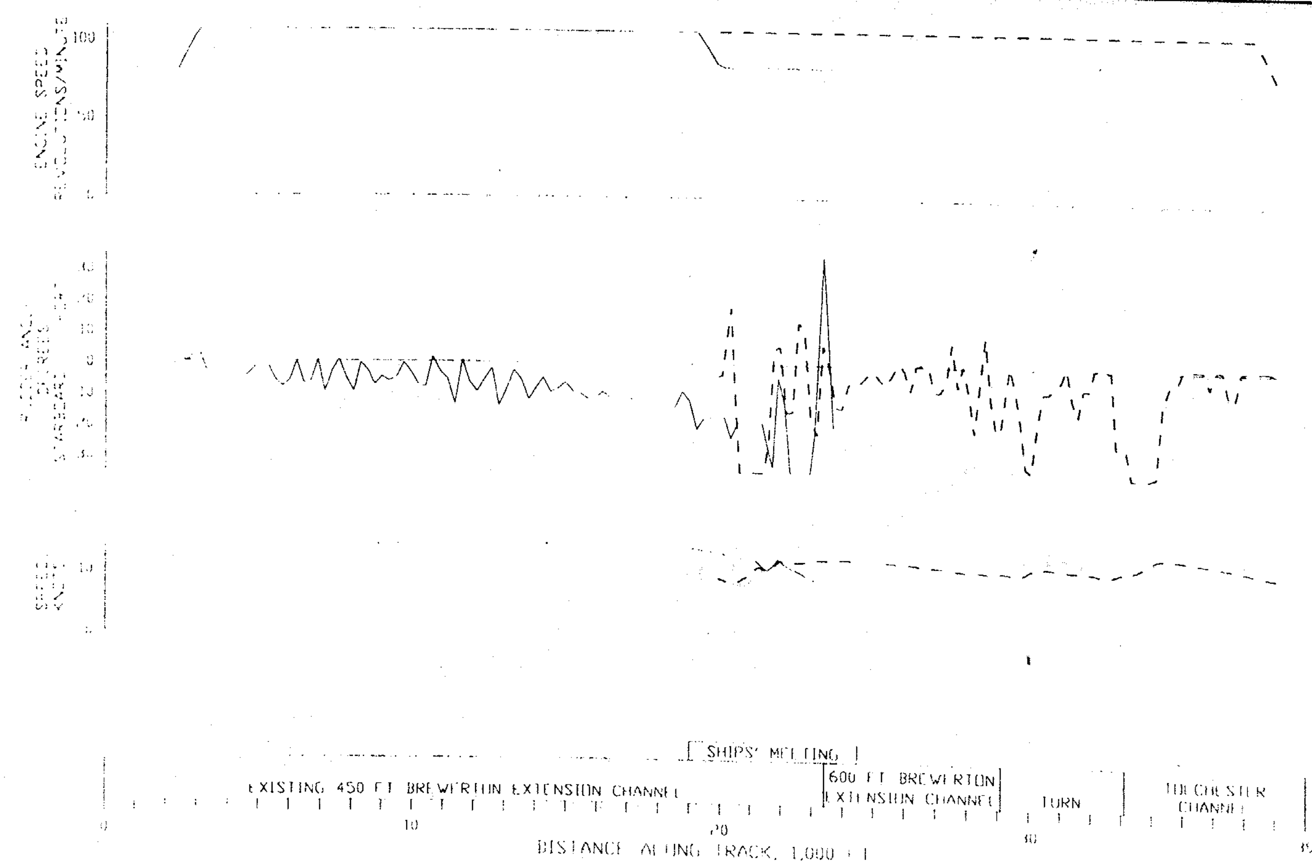


Plate 5

PRELIMINARY



——— OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 6

PRELIMINARY

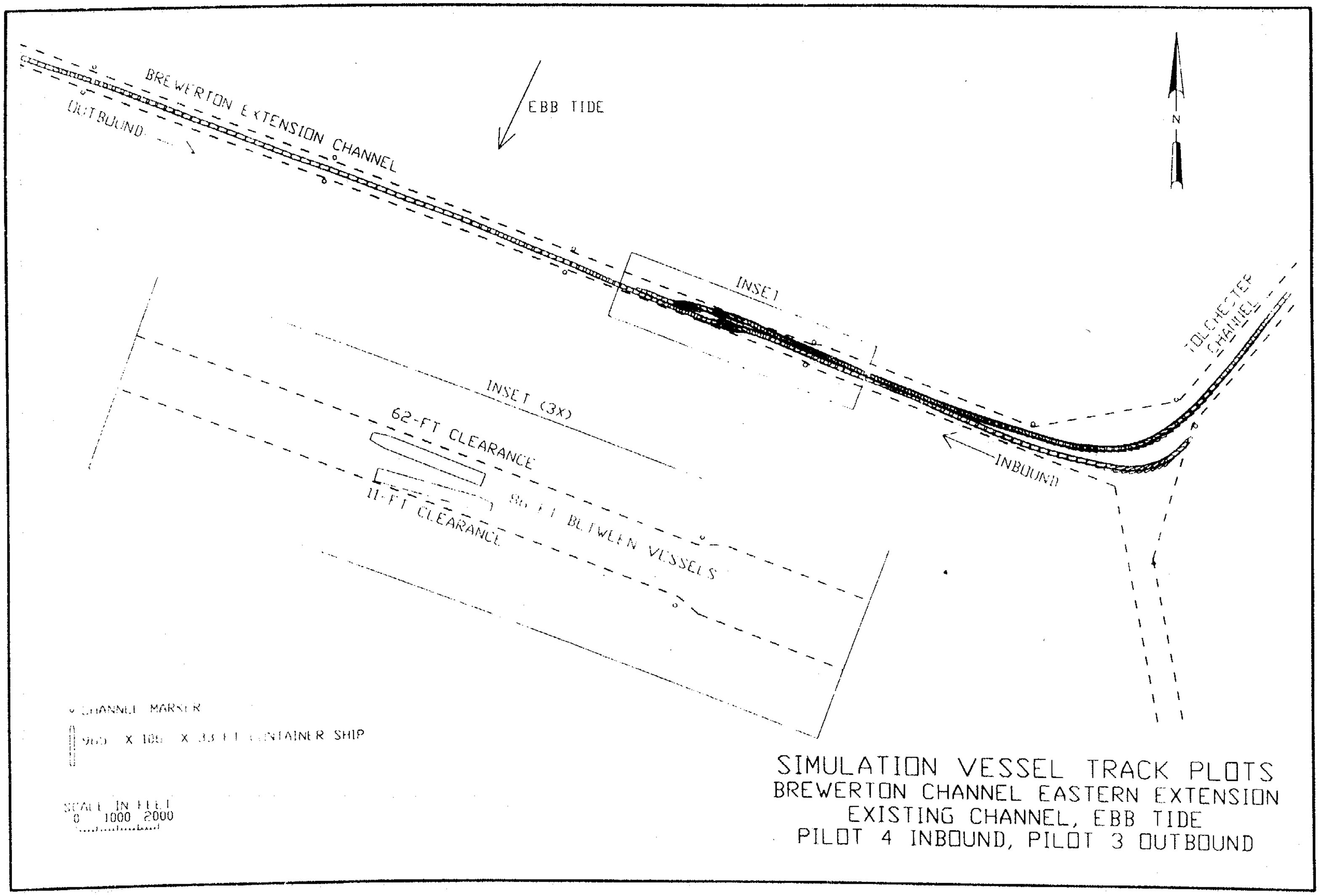


Plate 7

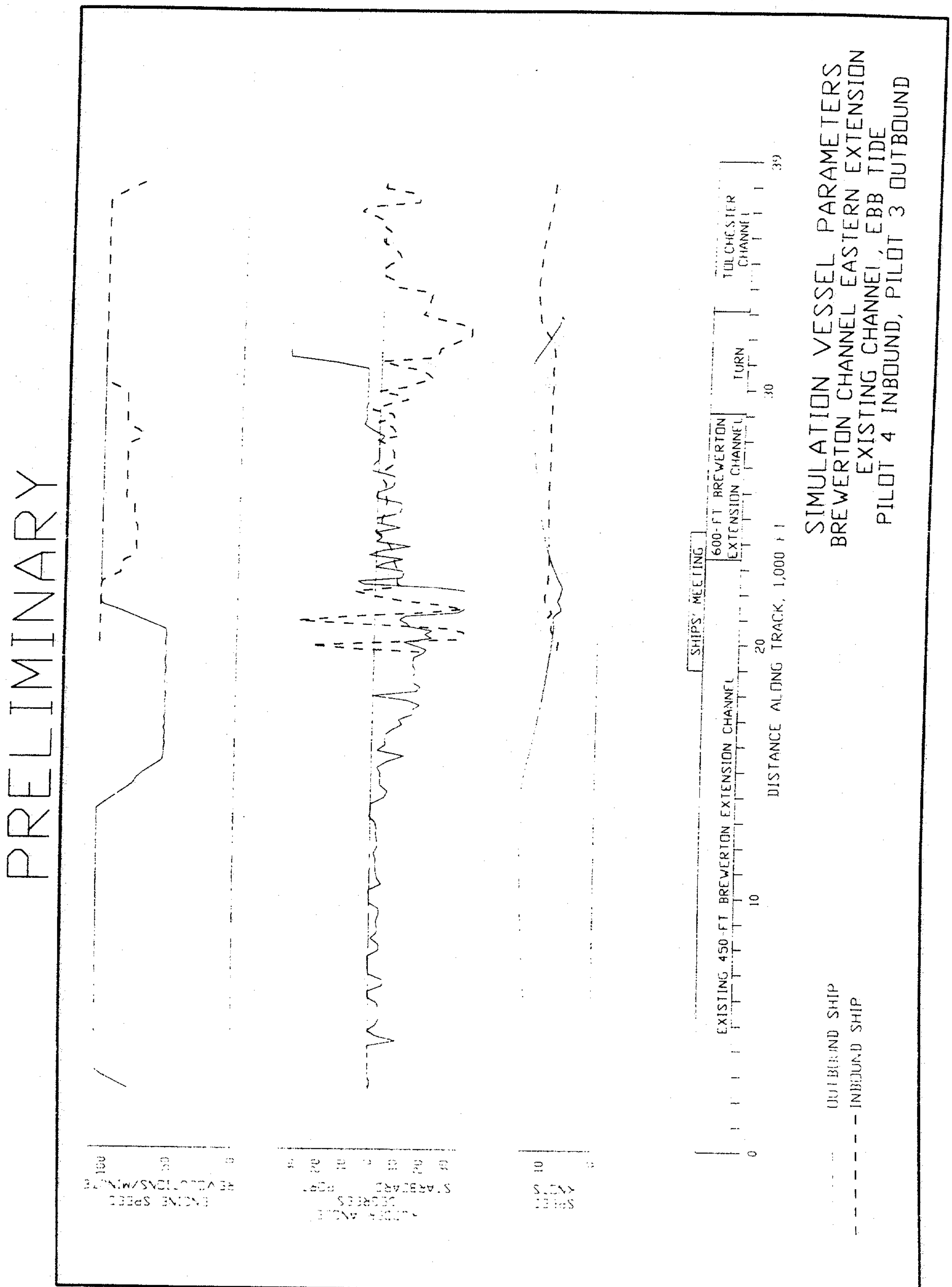

PRELIMINARY
SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND
EXISTING 450-FT BREWERTON EXTENSION CHANNEL
SHIPS' MEETING
600-FT BREWERTON EXTENSION CHANNEL
TURN
TOLCHESTER CHANNEL
DISTANCE ALONG TRACK, 1,000 FT
0
10
20
30
39
OUTBOUND SHIP
INBOUND SHIP

Plate 8

PRELIMINARY

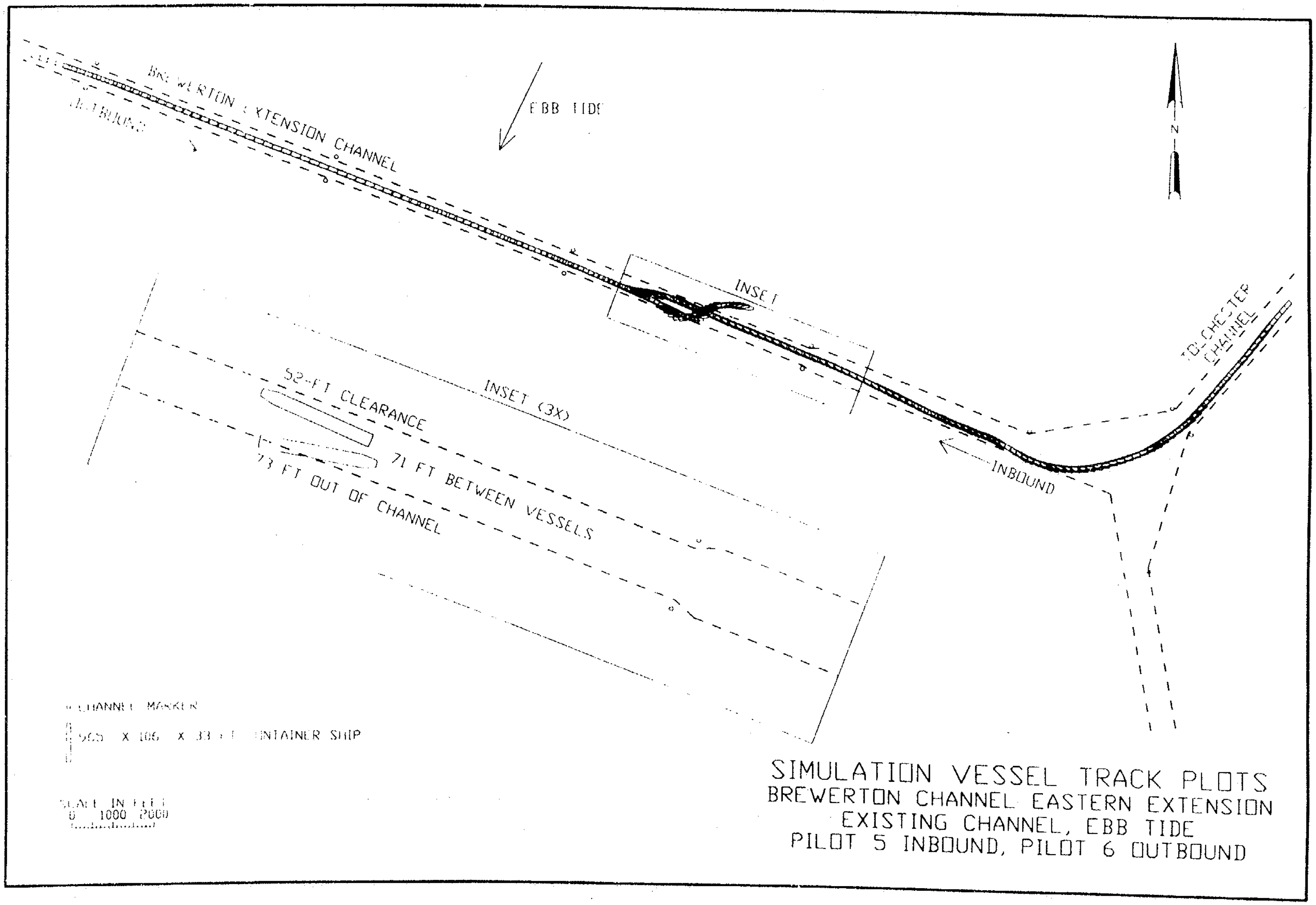
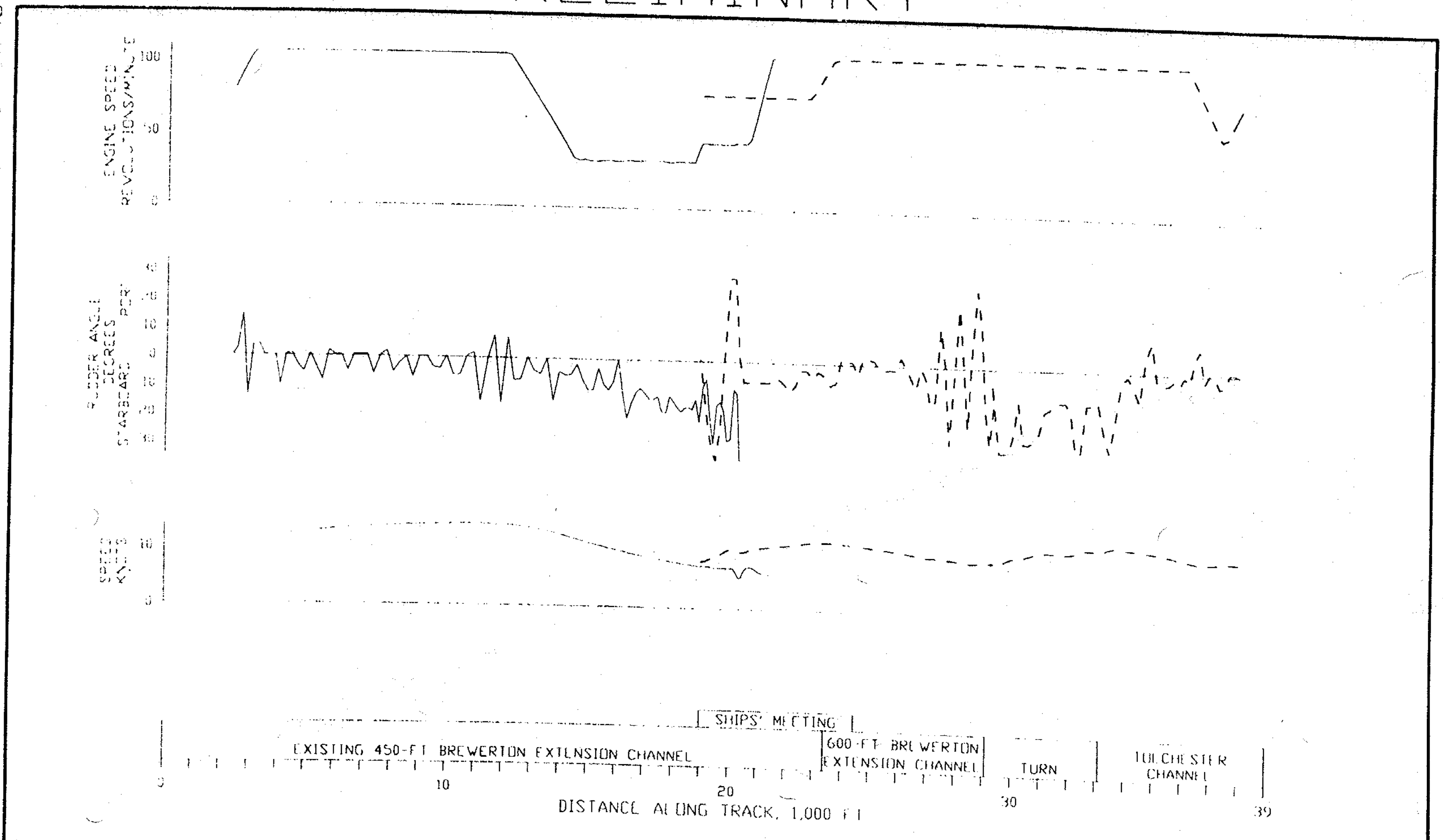


Plate 9

PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 10

PRELIMINARY

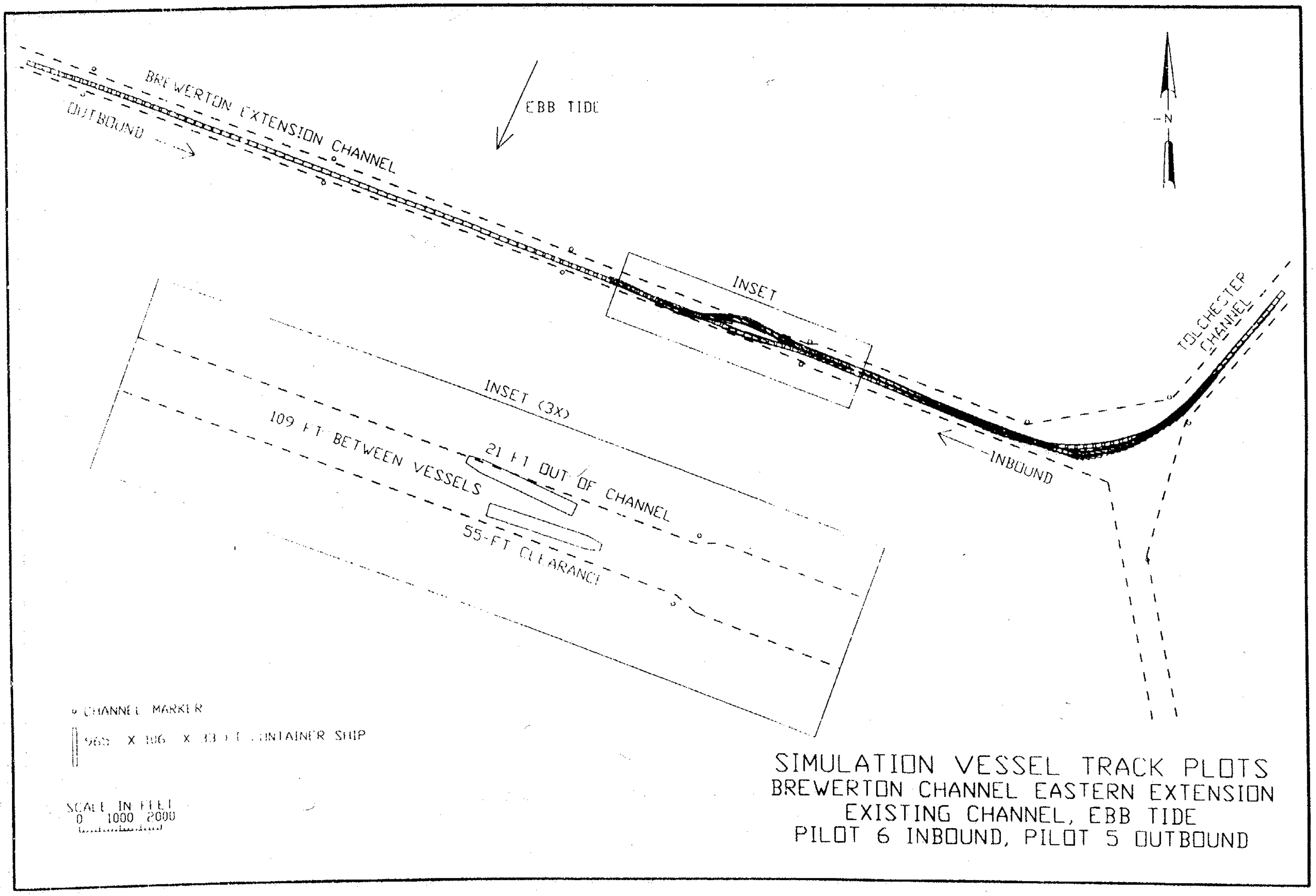
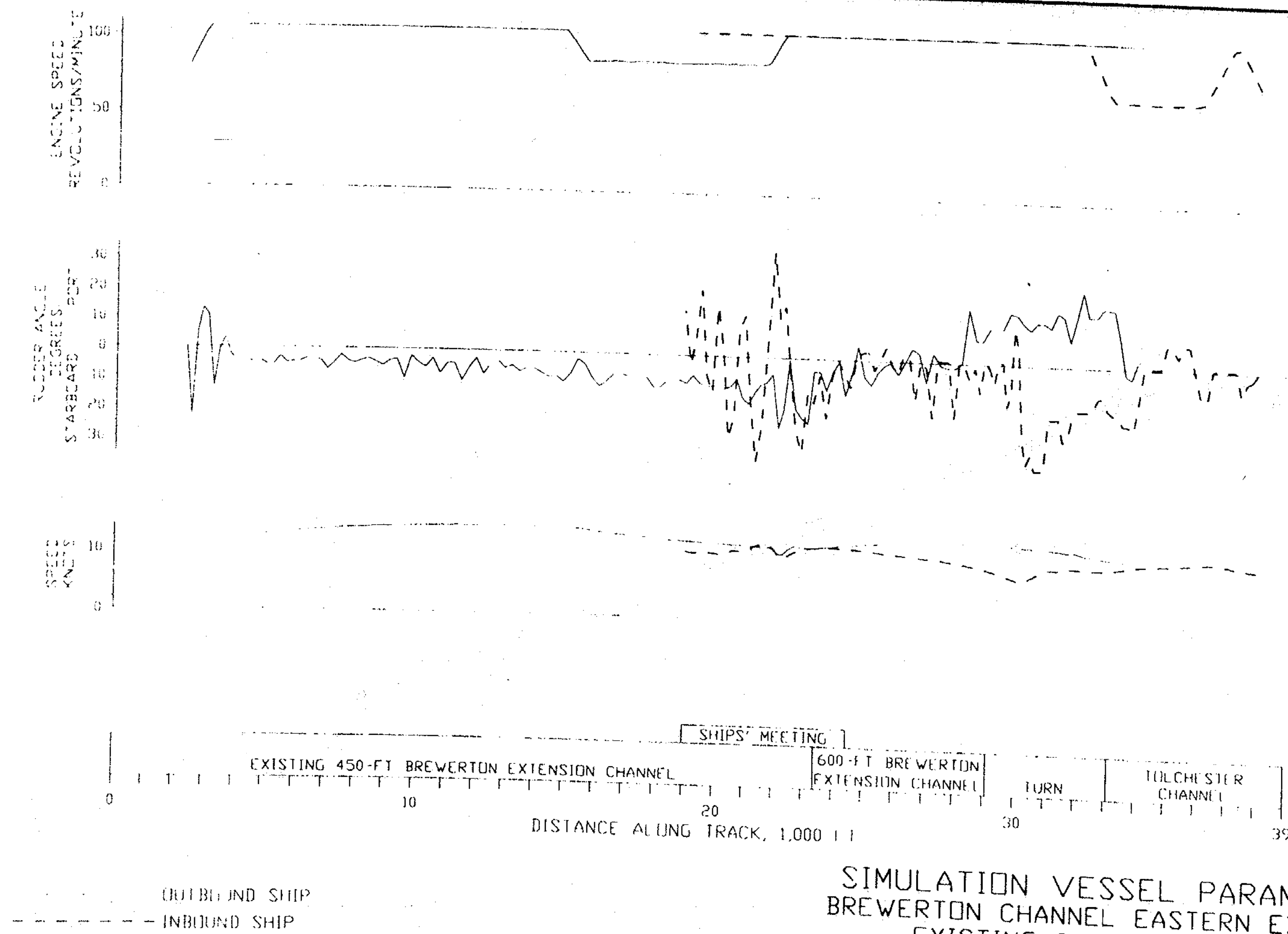


Plate 11

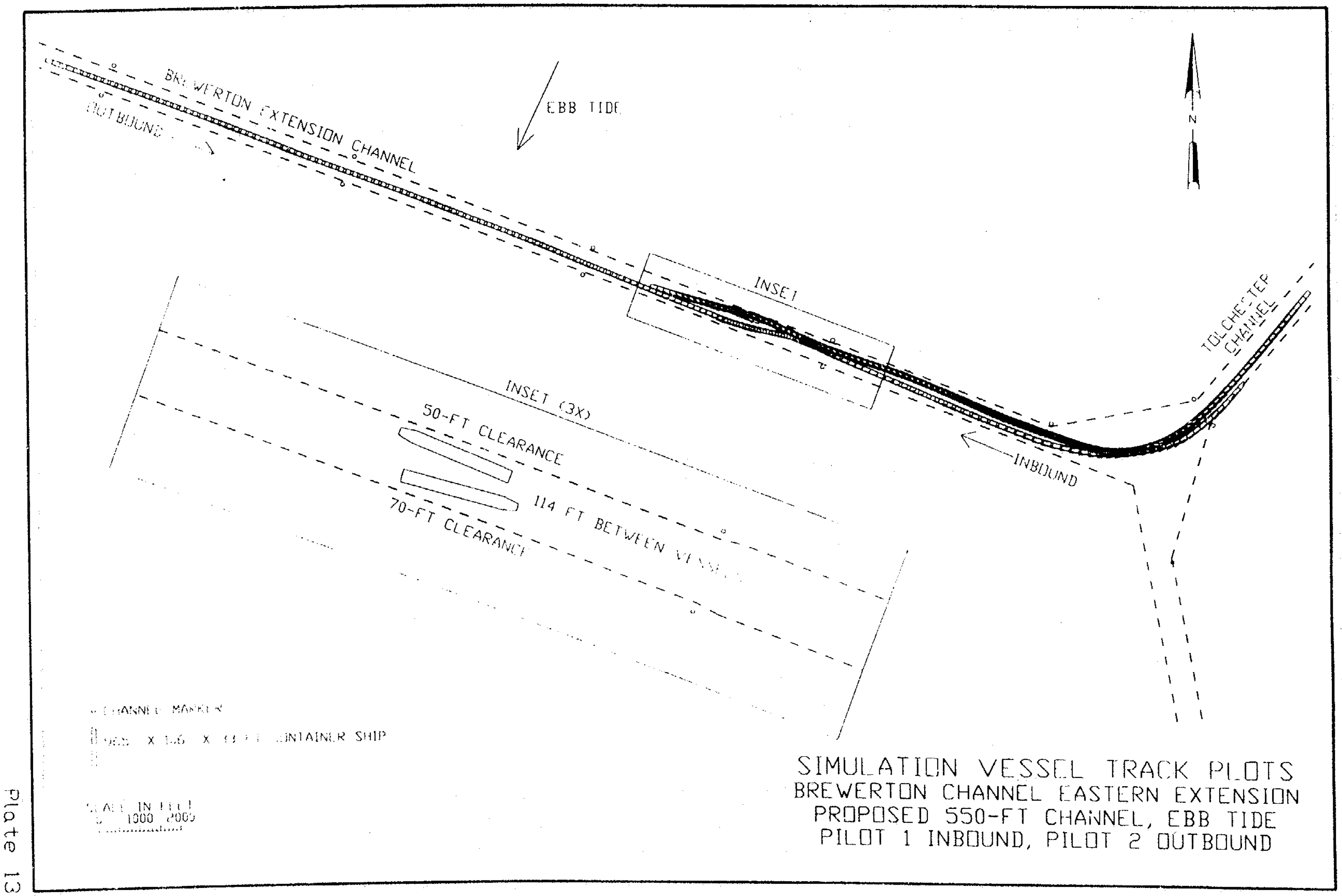
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 12

PRELIMINARY



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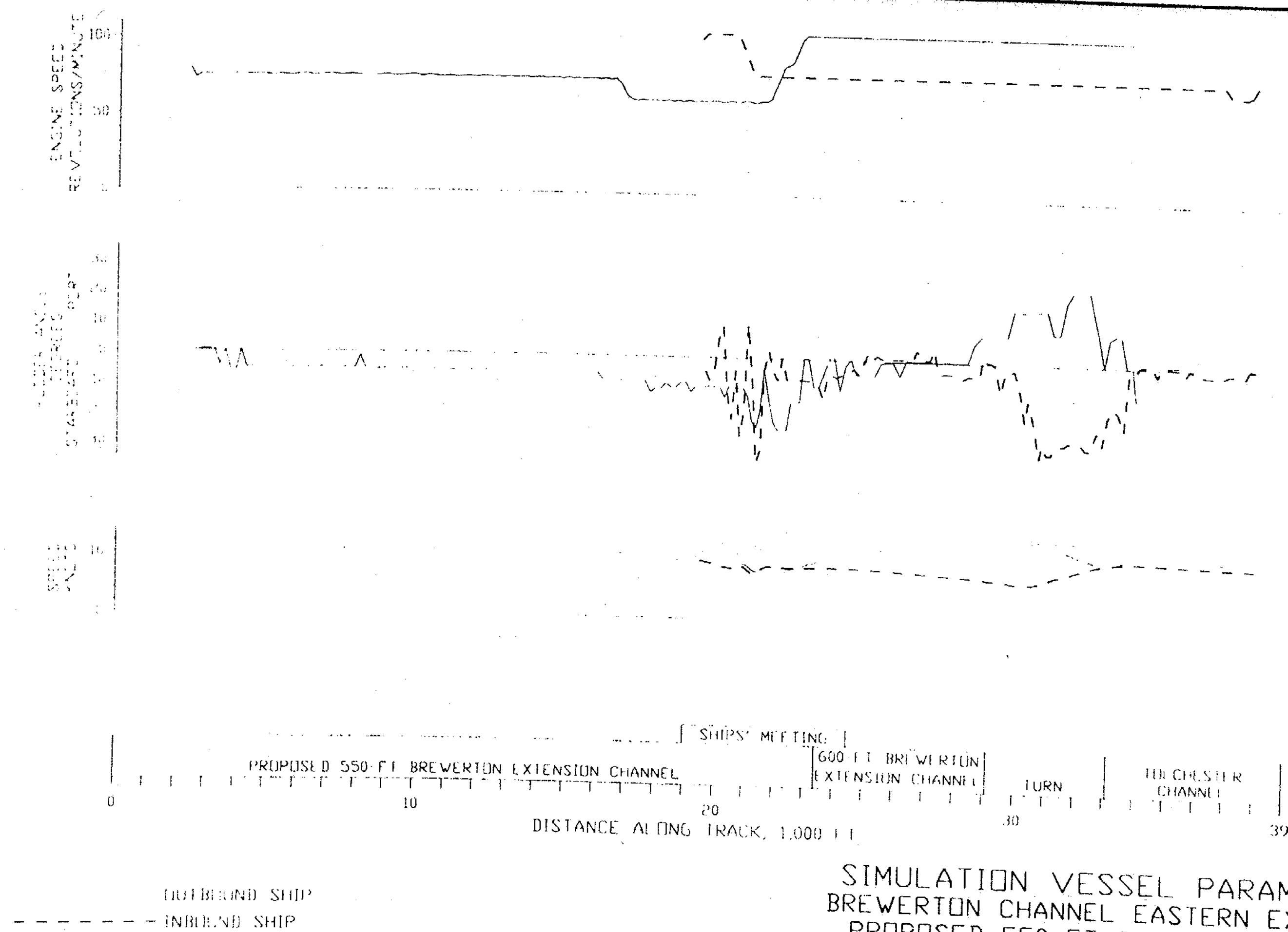
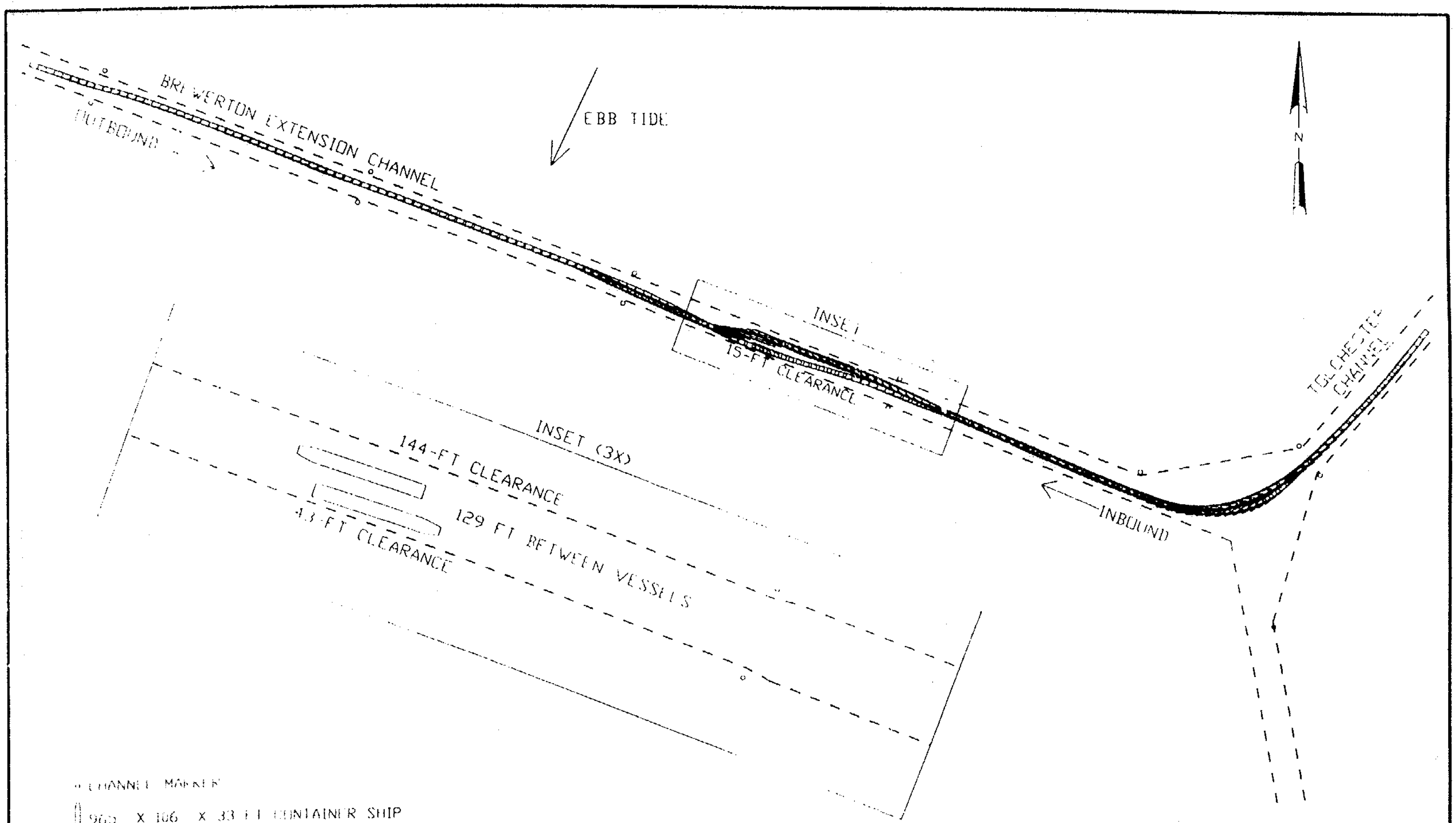


SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

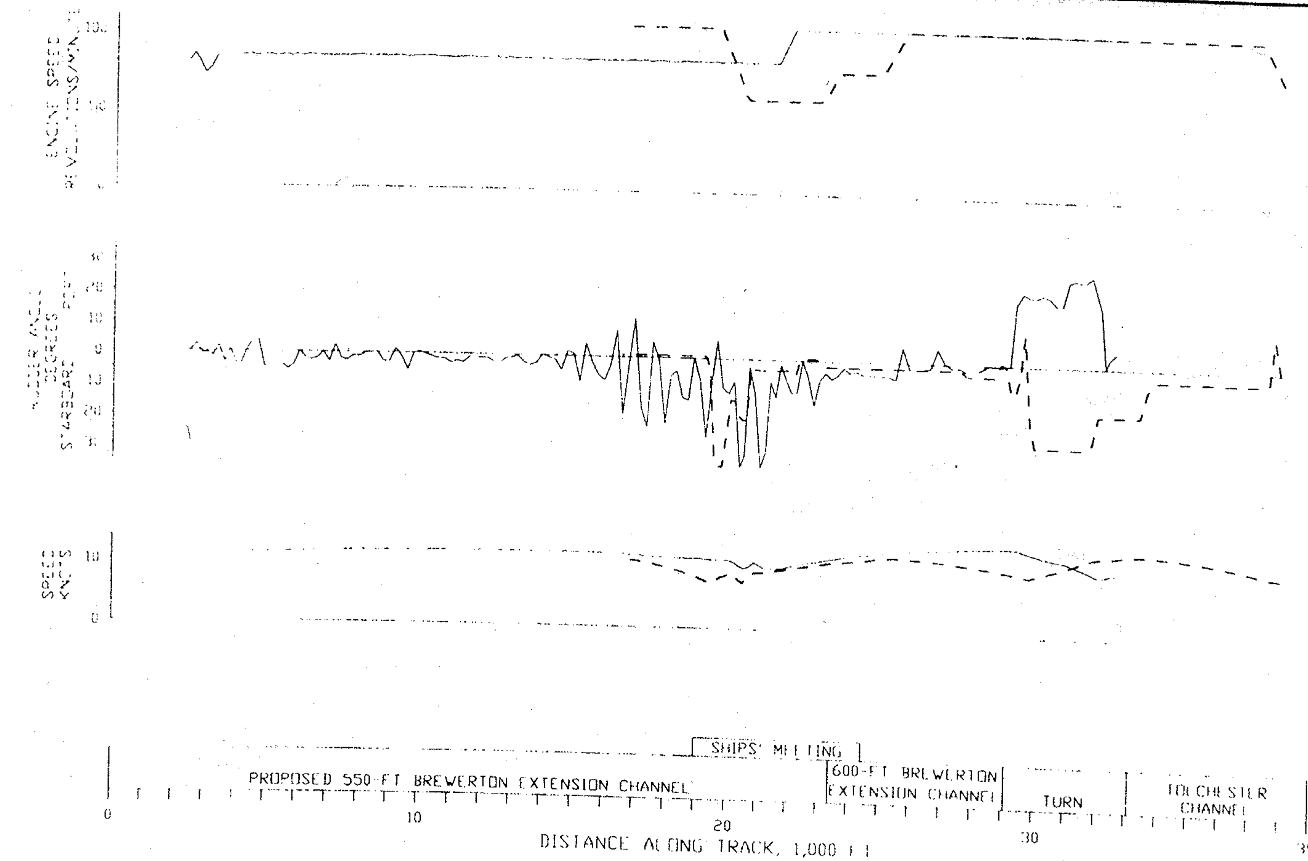
Plate 14

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

PRELIMINARY

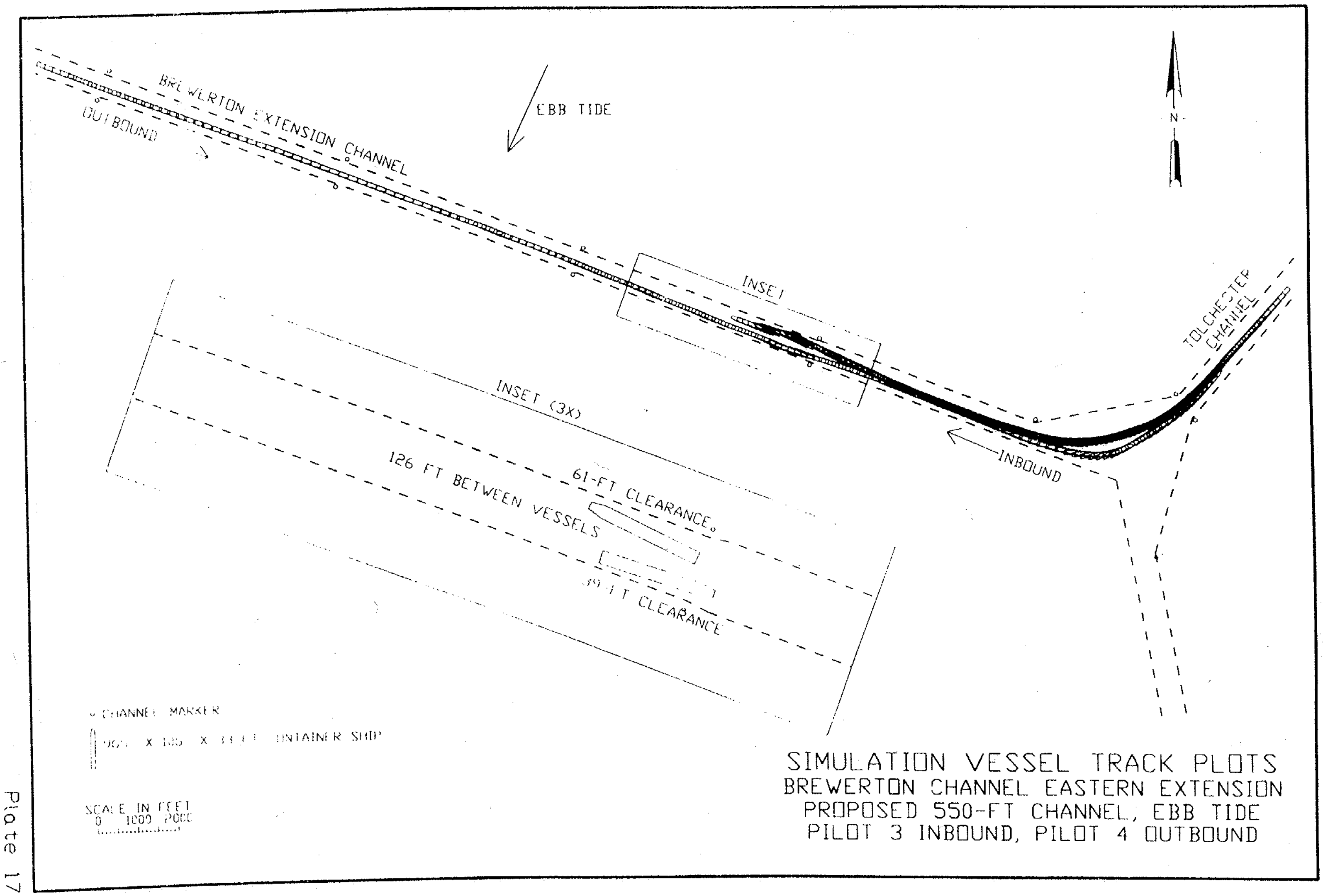


OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

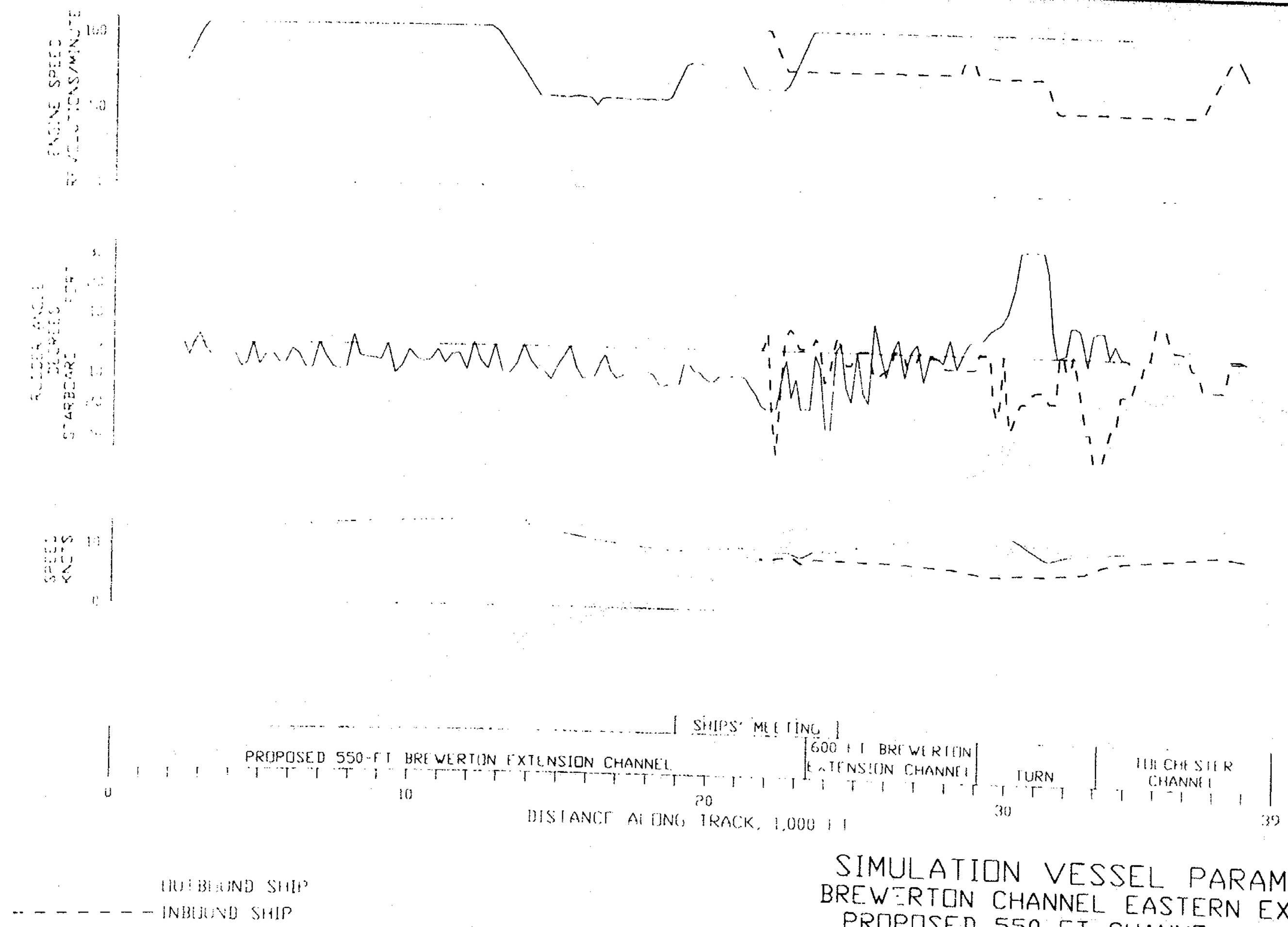
Plate 16

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

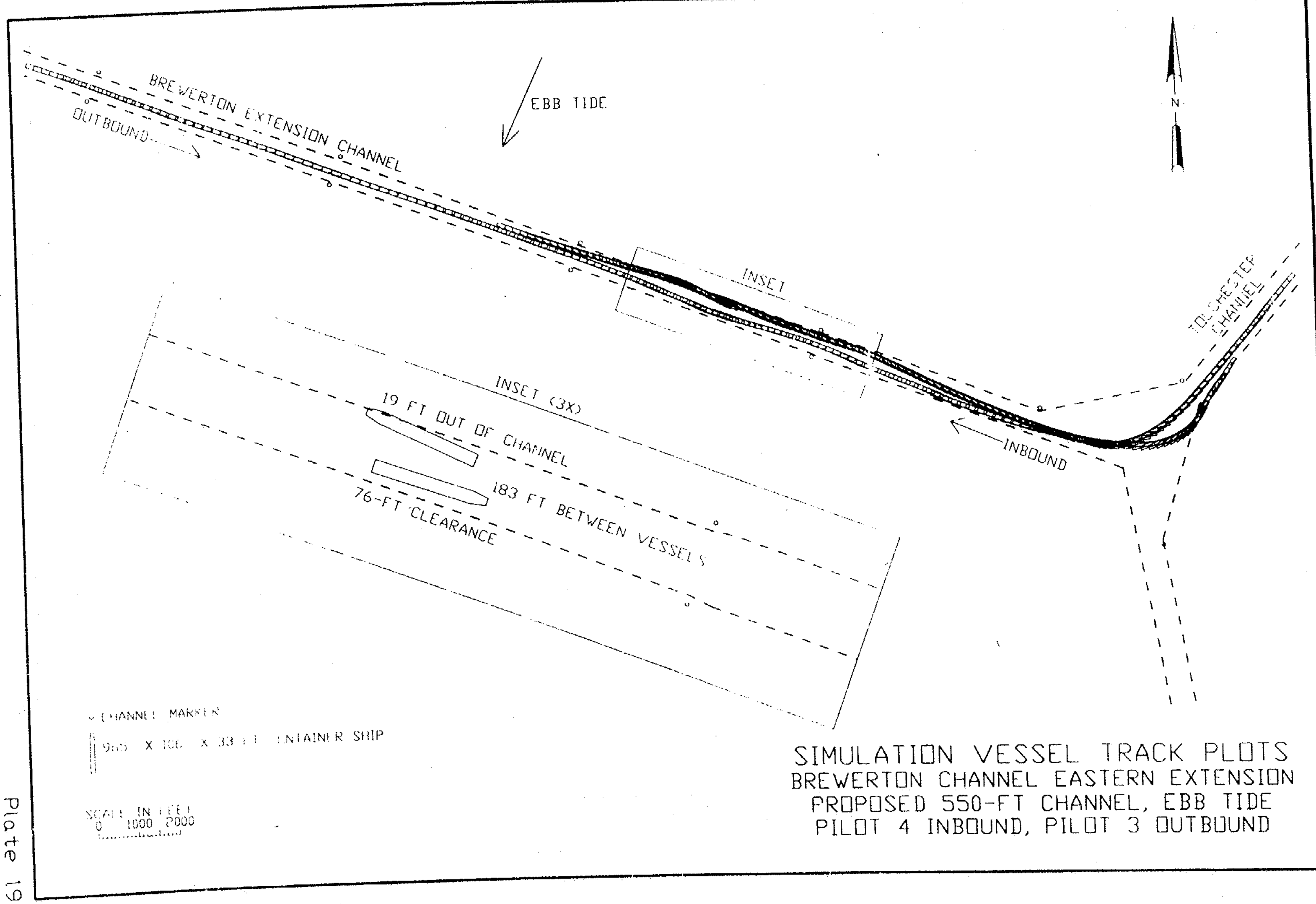
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

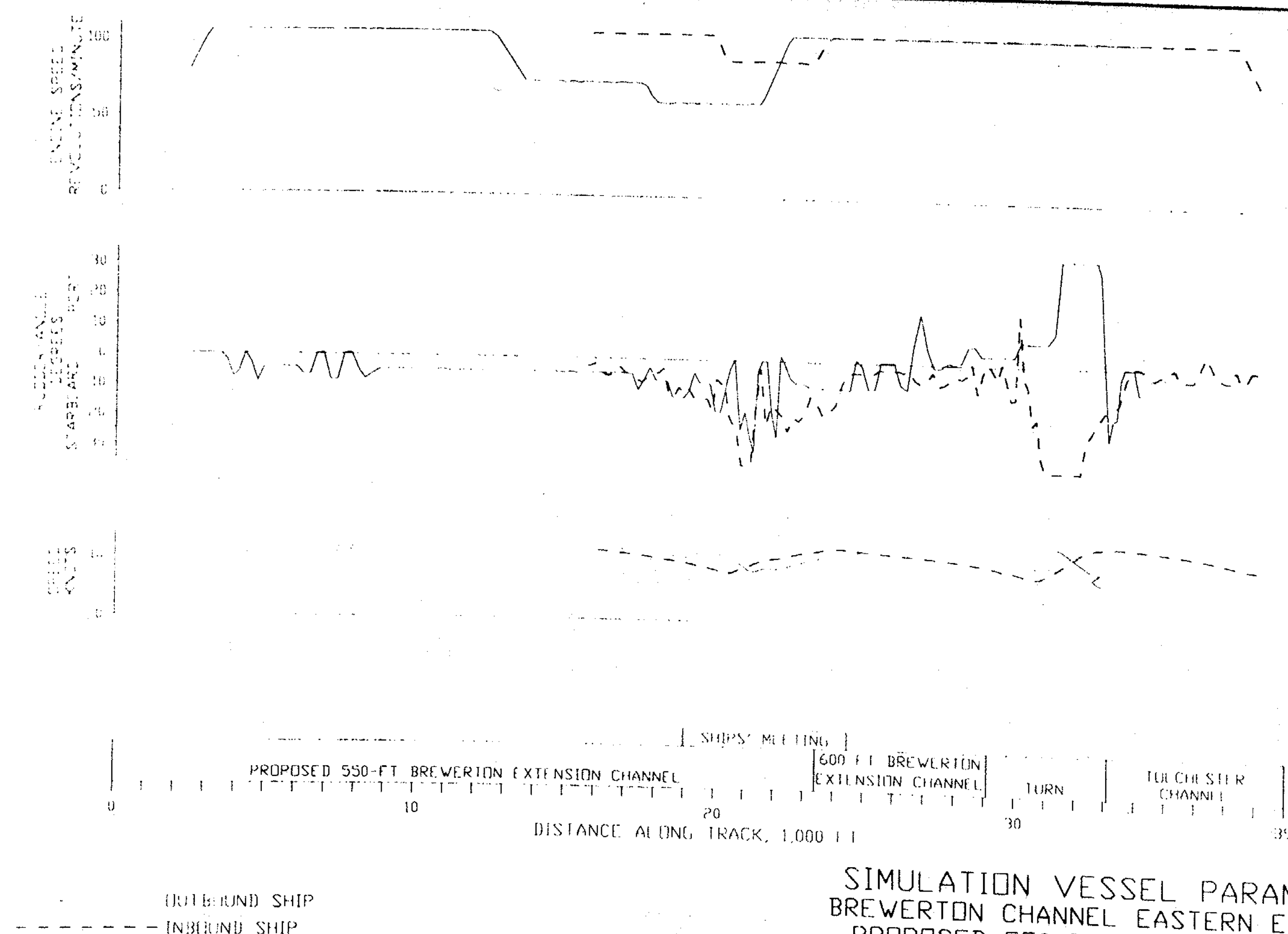
Plate 18

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

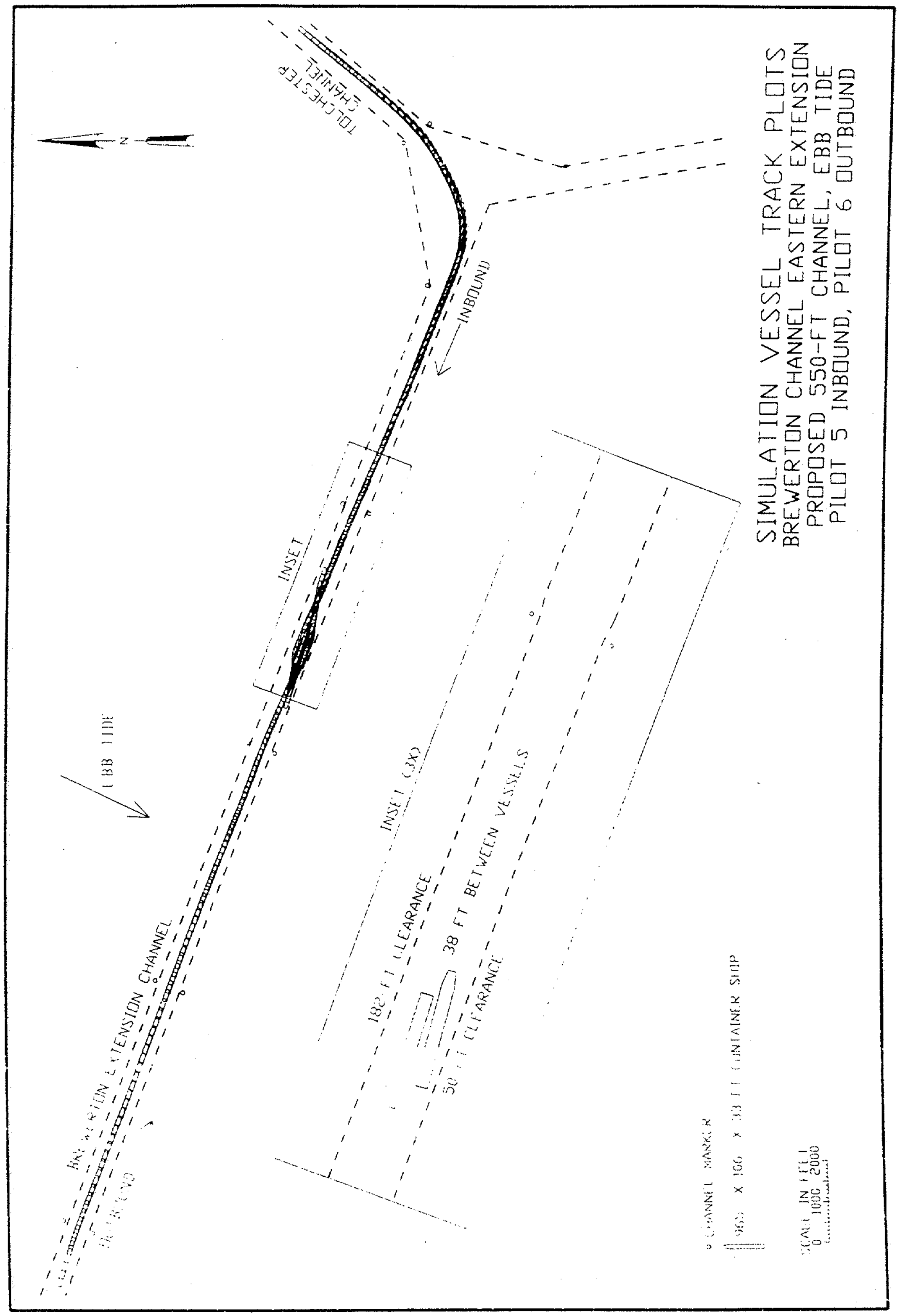
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 20

PRELIMINARY



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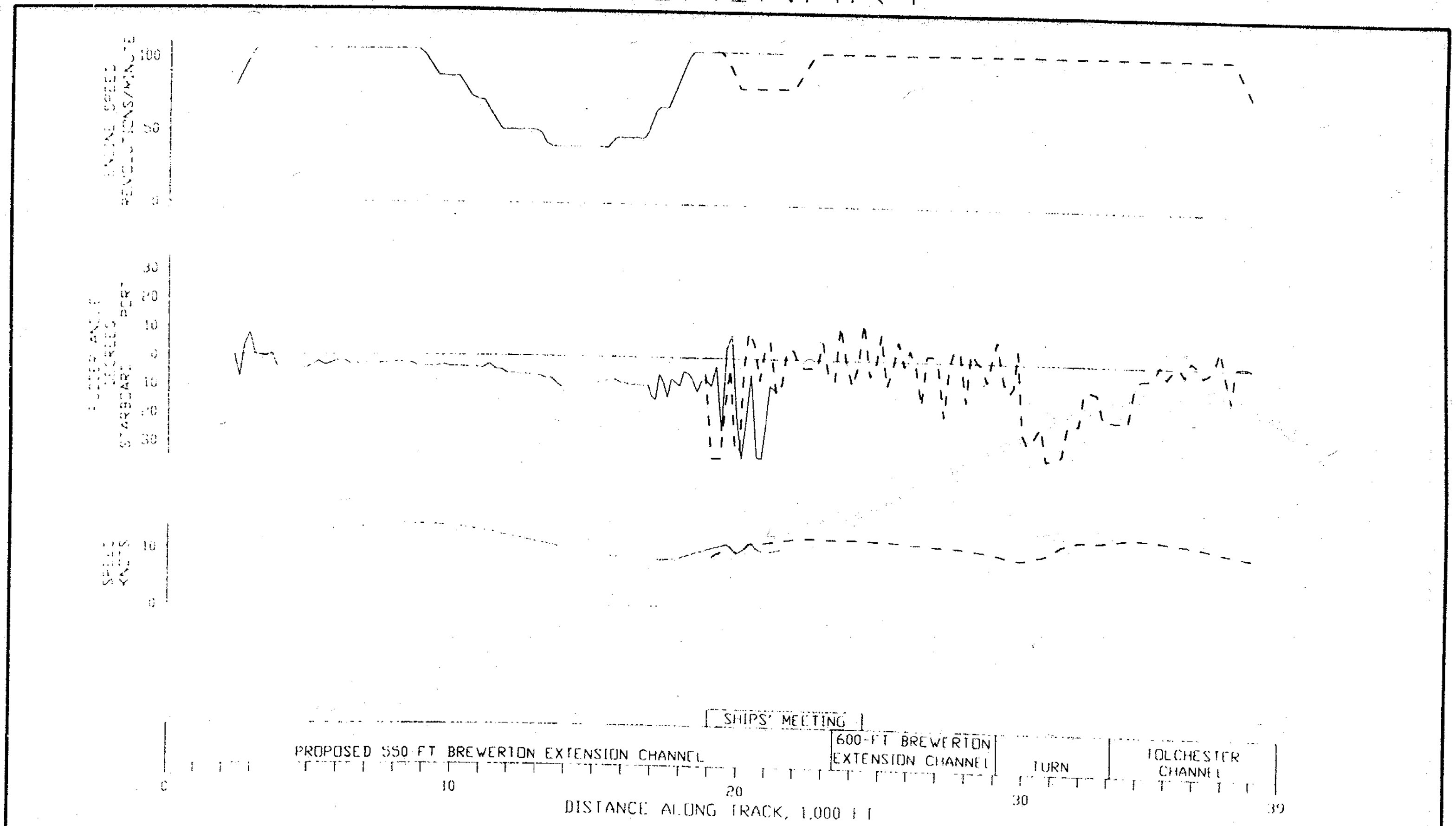


SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 22

PRELIMINARY

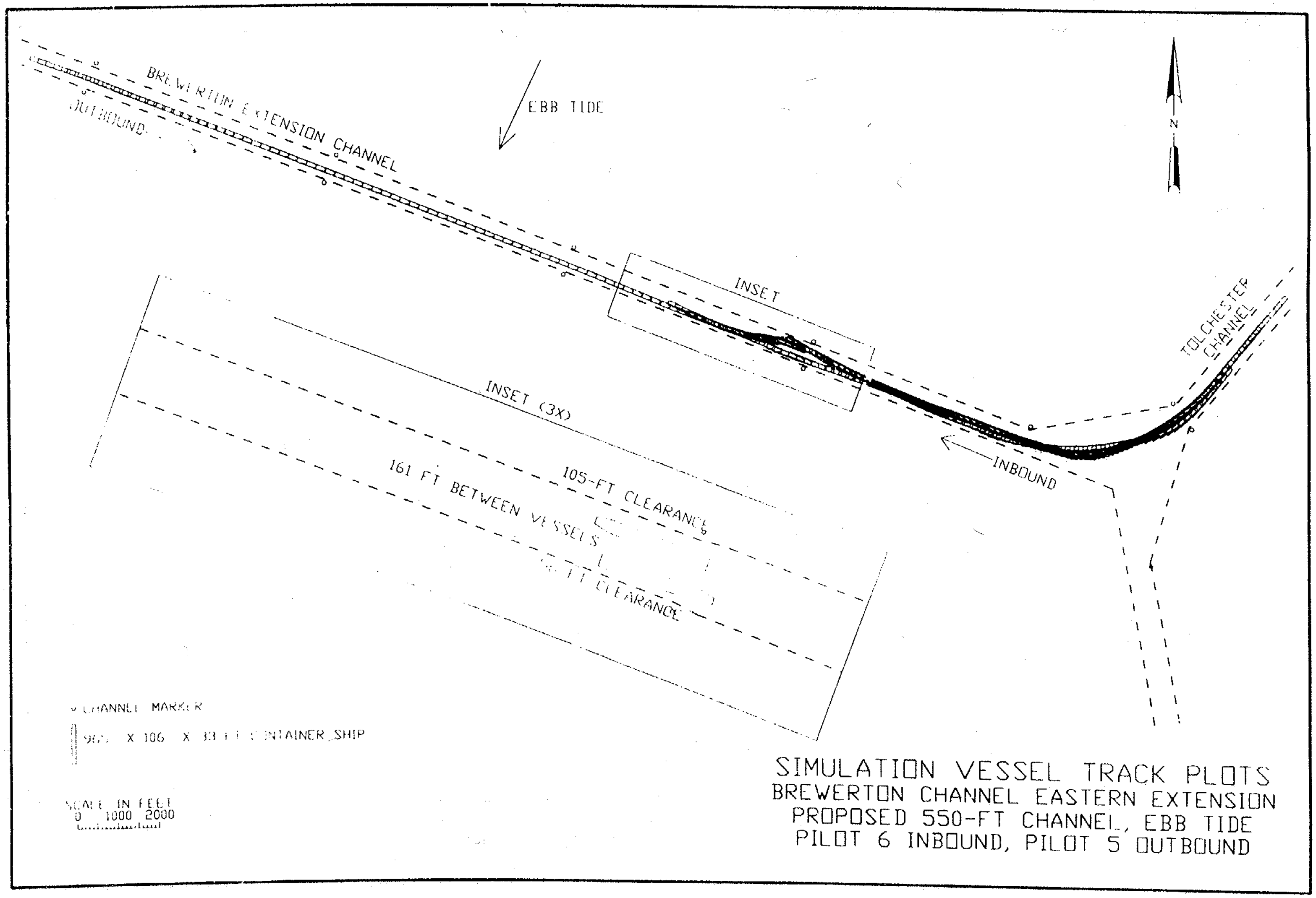


Plate 23

PRELIMINARY

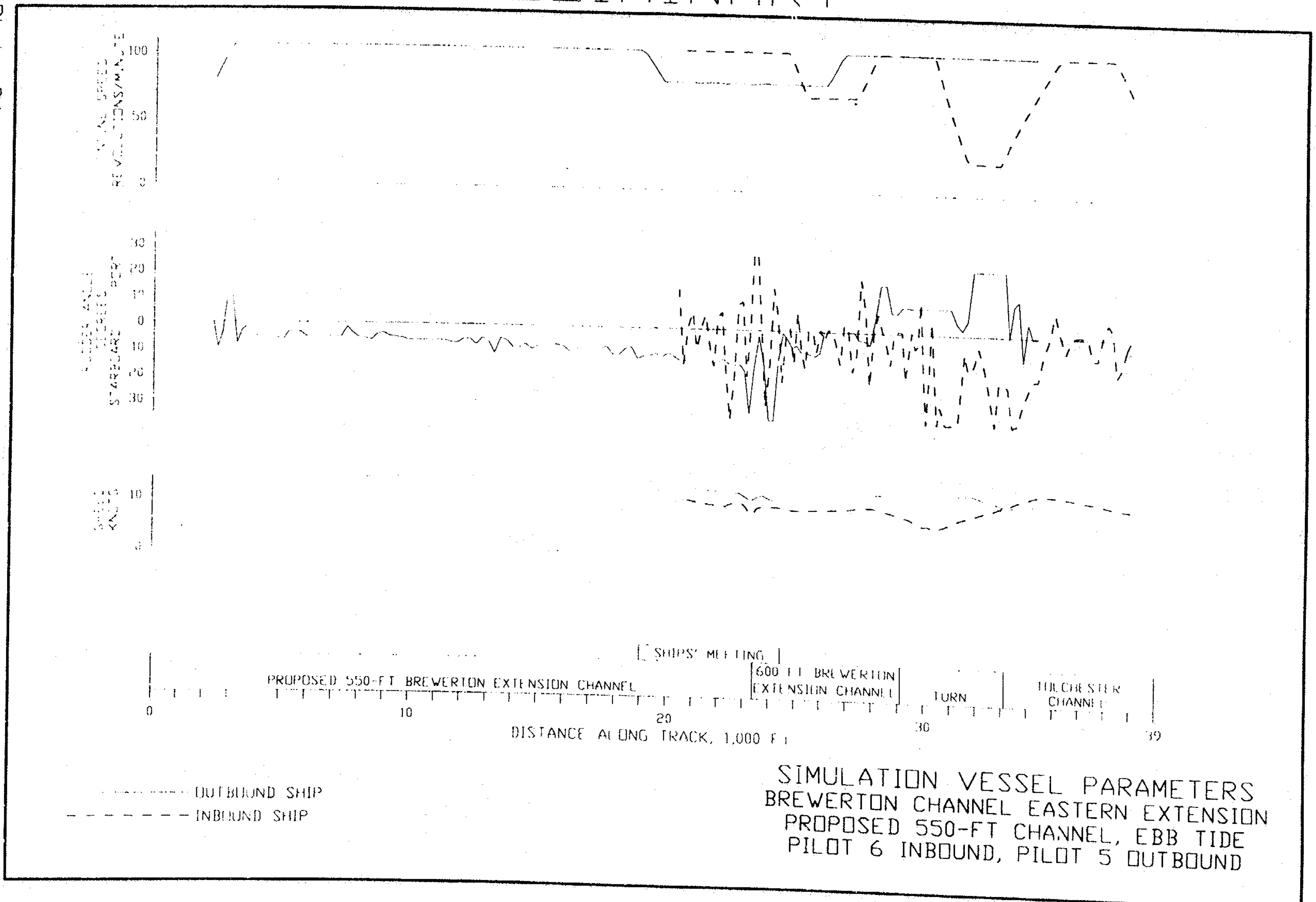


Plate 24

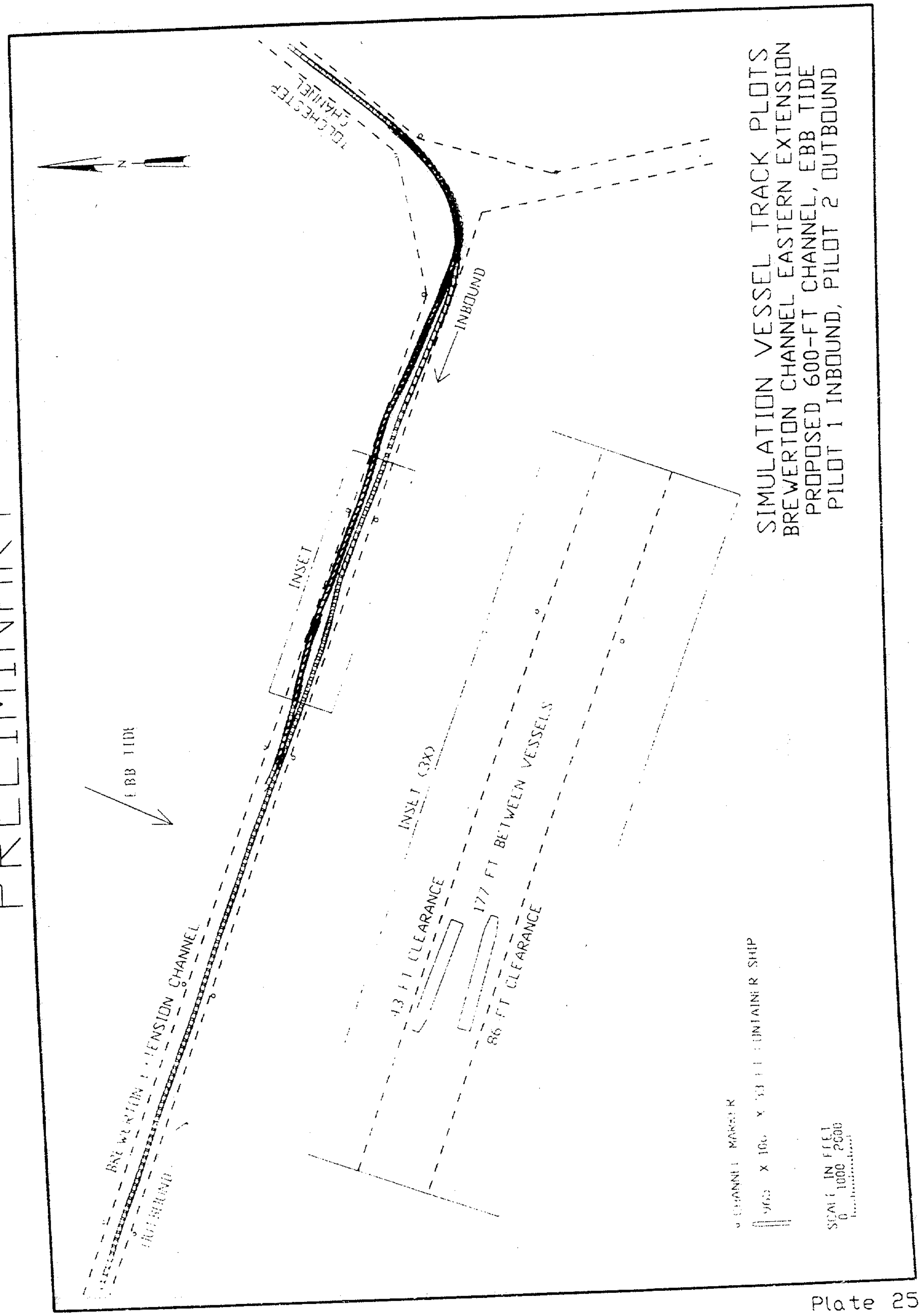
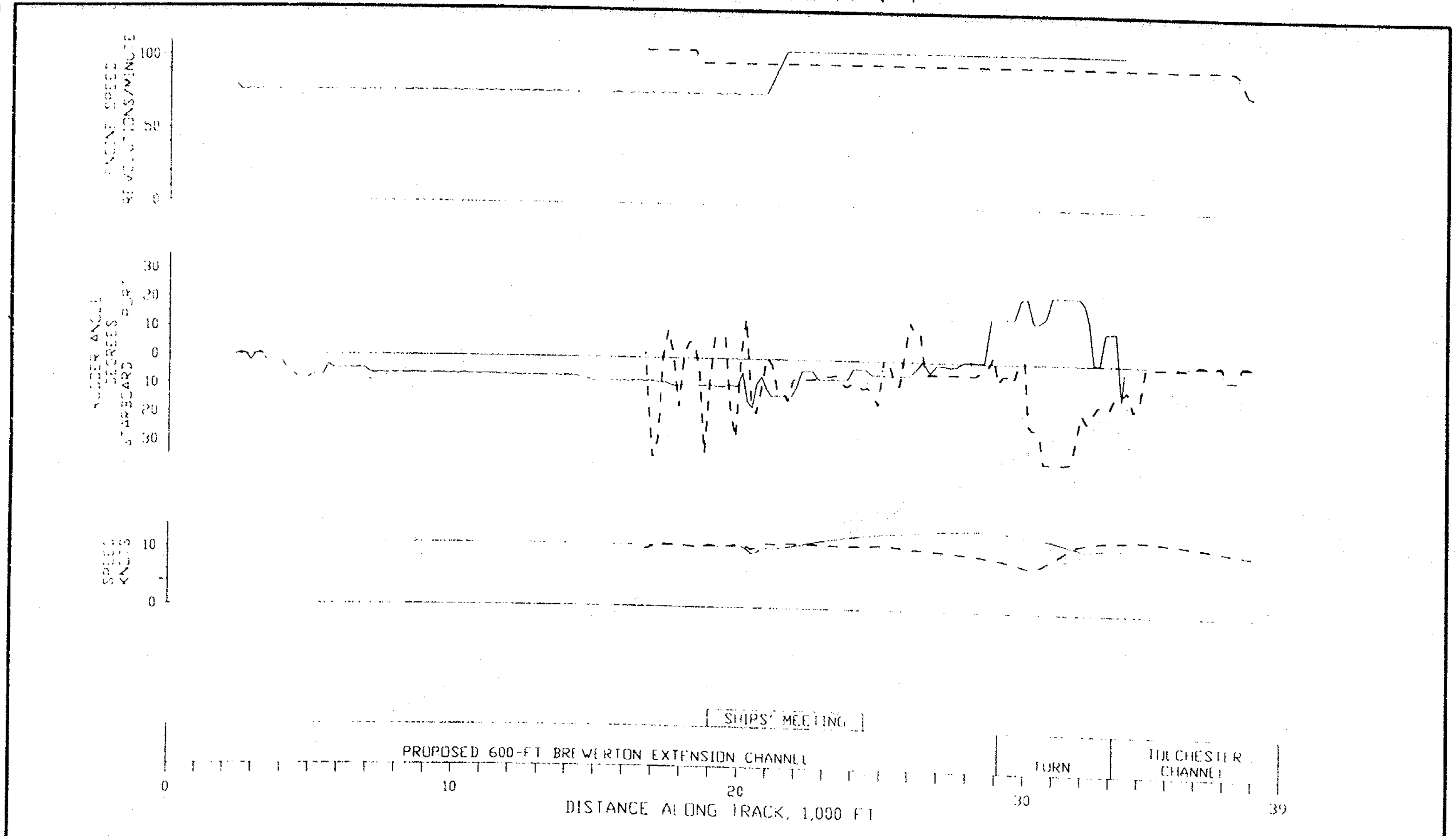

PRELIMINARY
SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND
N
TOLCHESTER CHANNEL
INBOUND
INSET
INSET (3X)
EBB TIDE
177 FT BETWEEN VESSELS
43 FT CLEARANCE
86 FT CLEARANCE
OUTBOUND
SCALE IN FEET
0 1000 2000

Plate 25

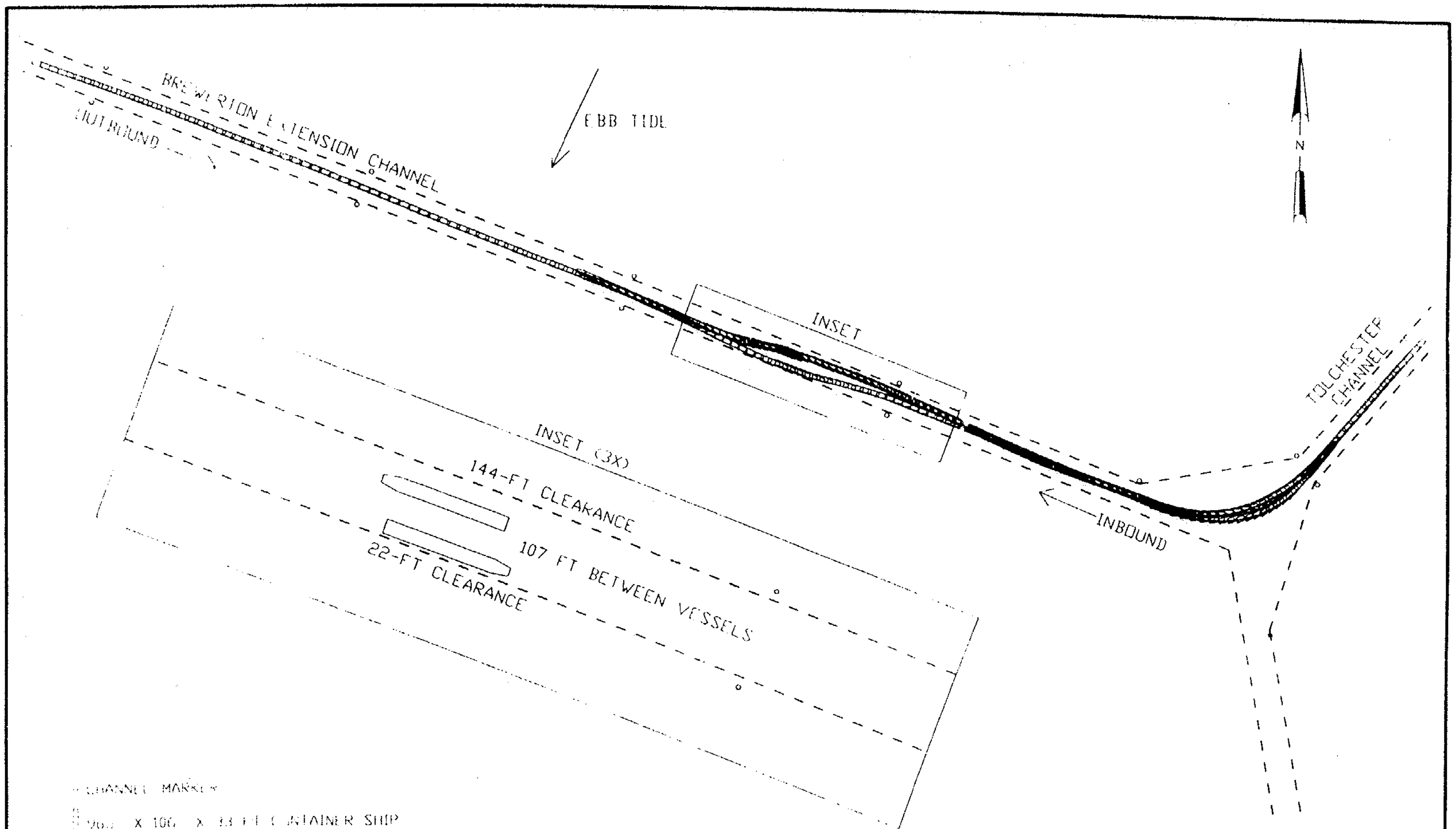
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

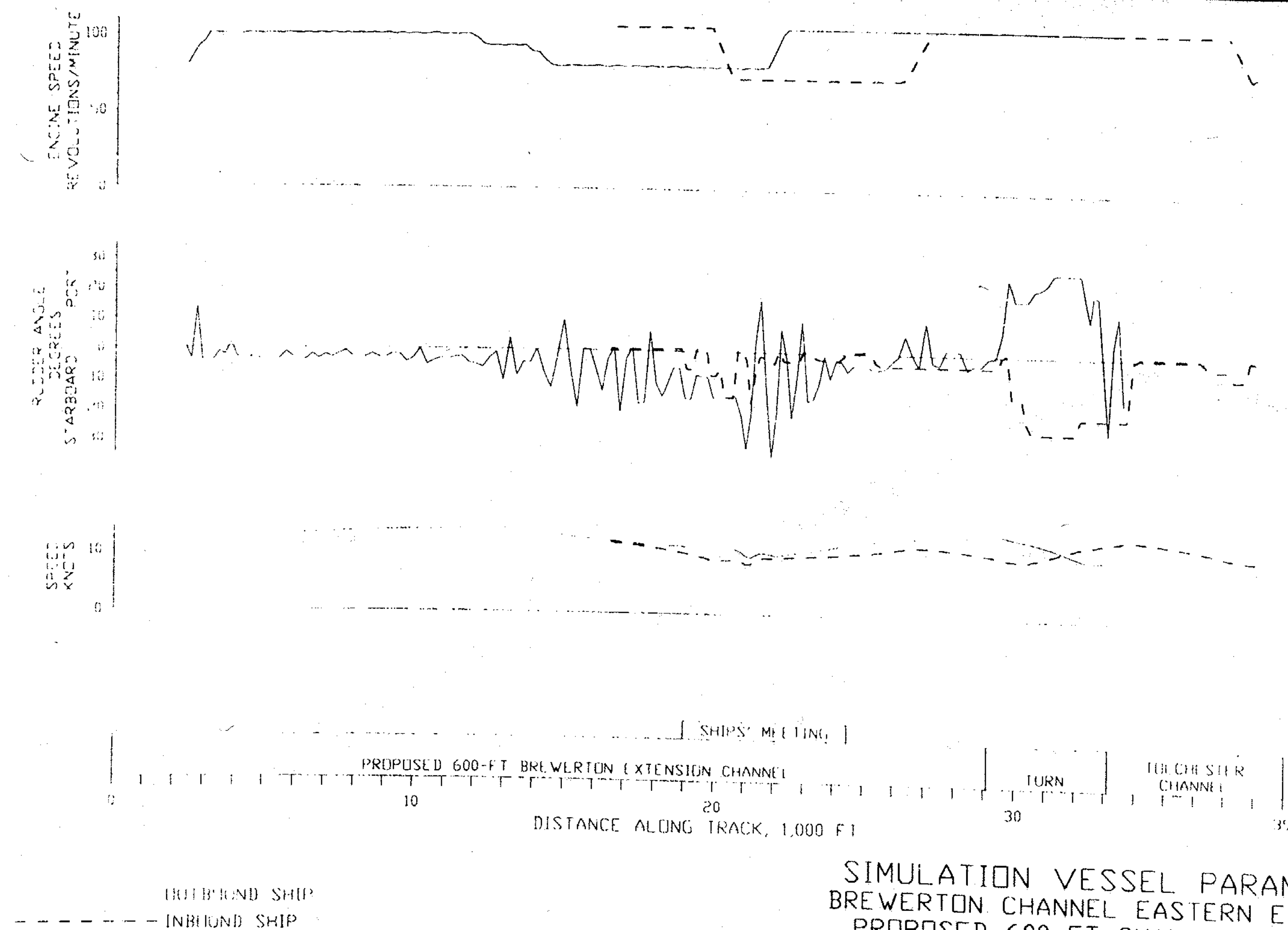
Plate 26

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

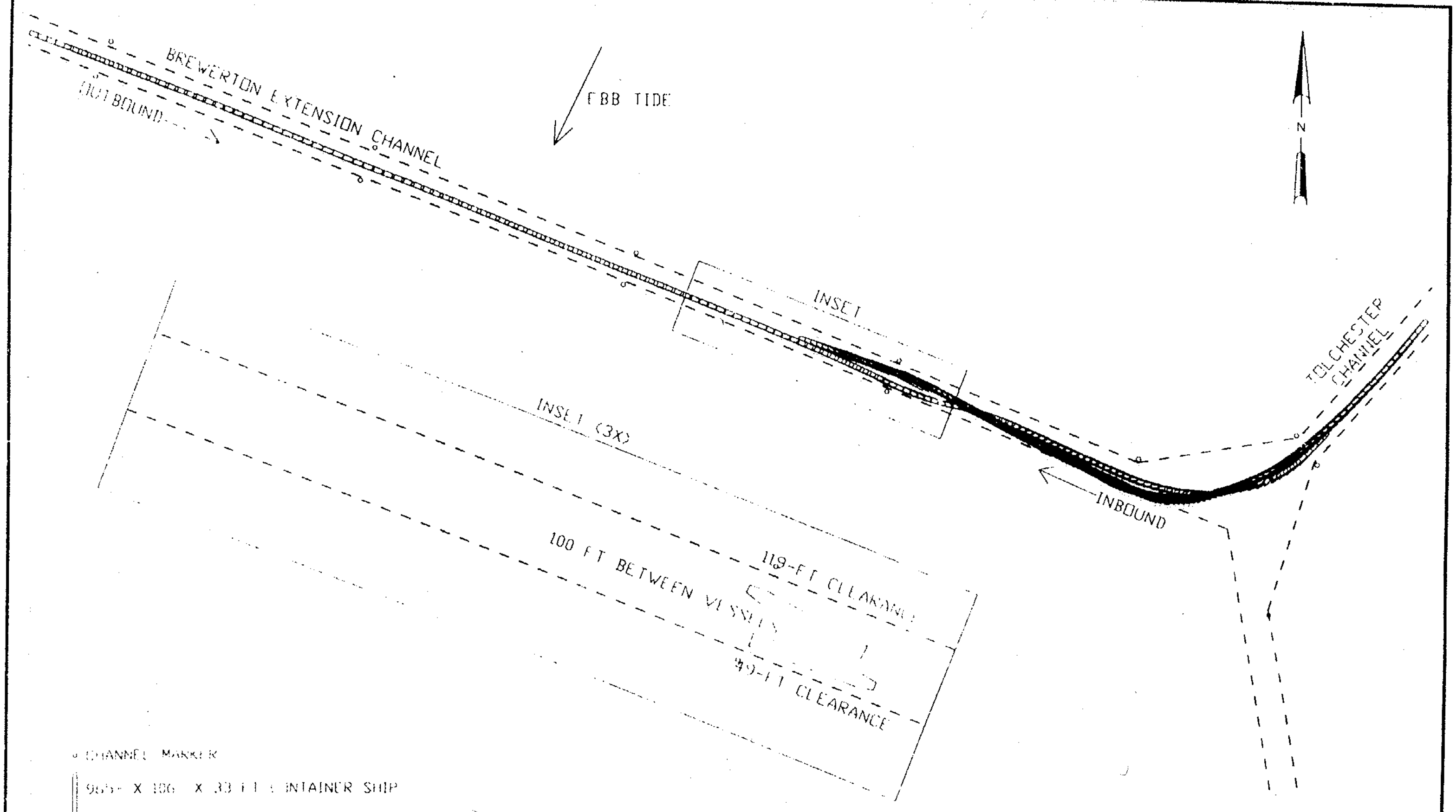
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

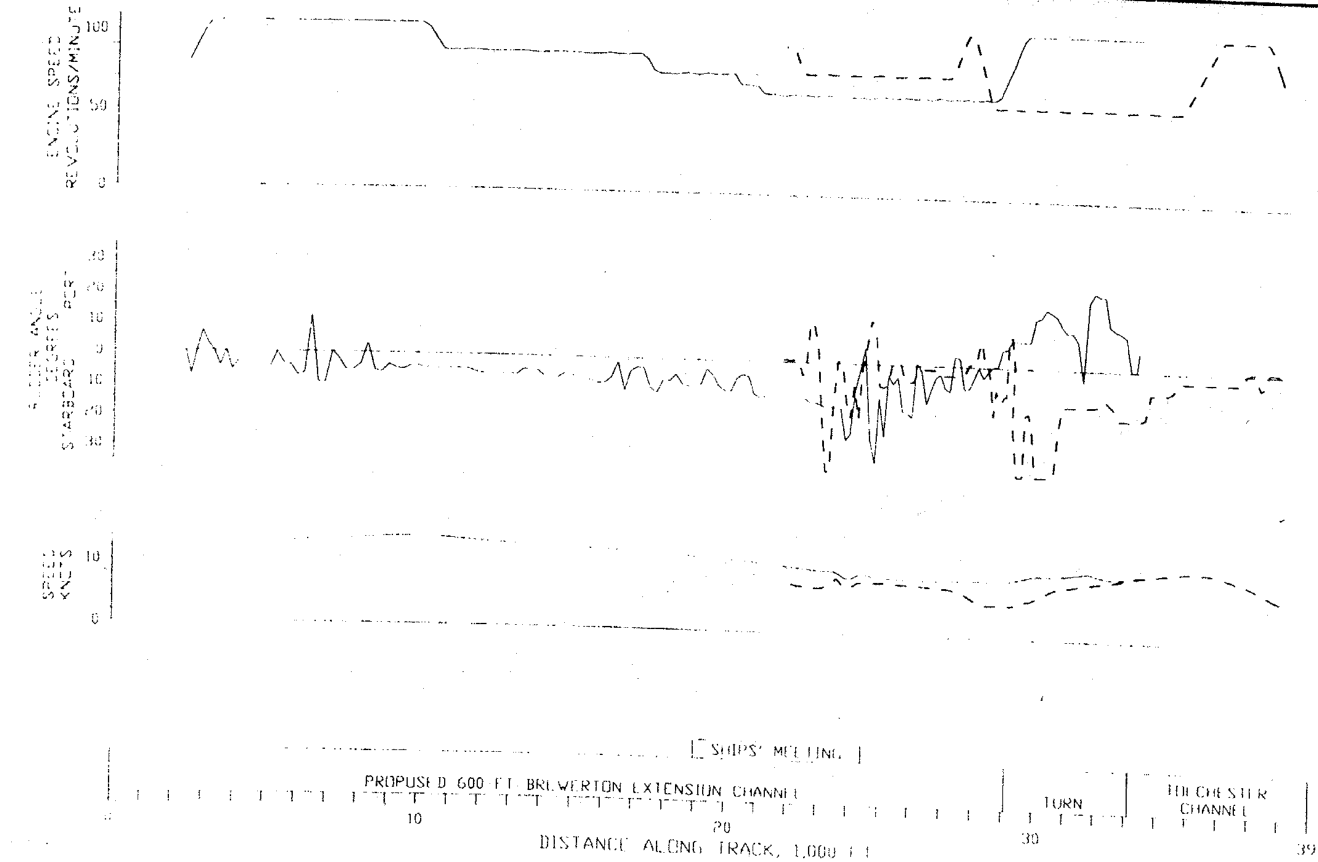
Plate 28

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY



OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 30

PRELIMINARY

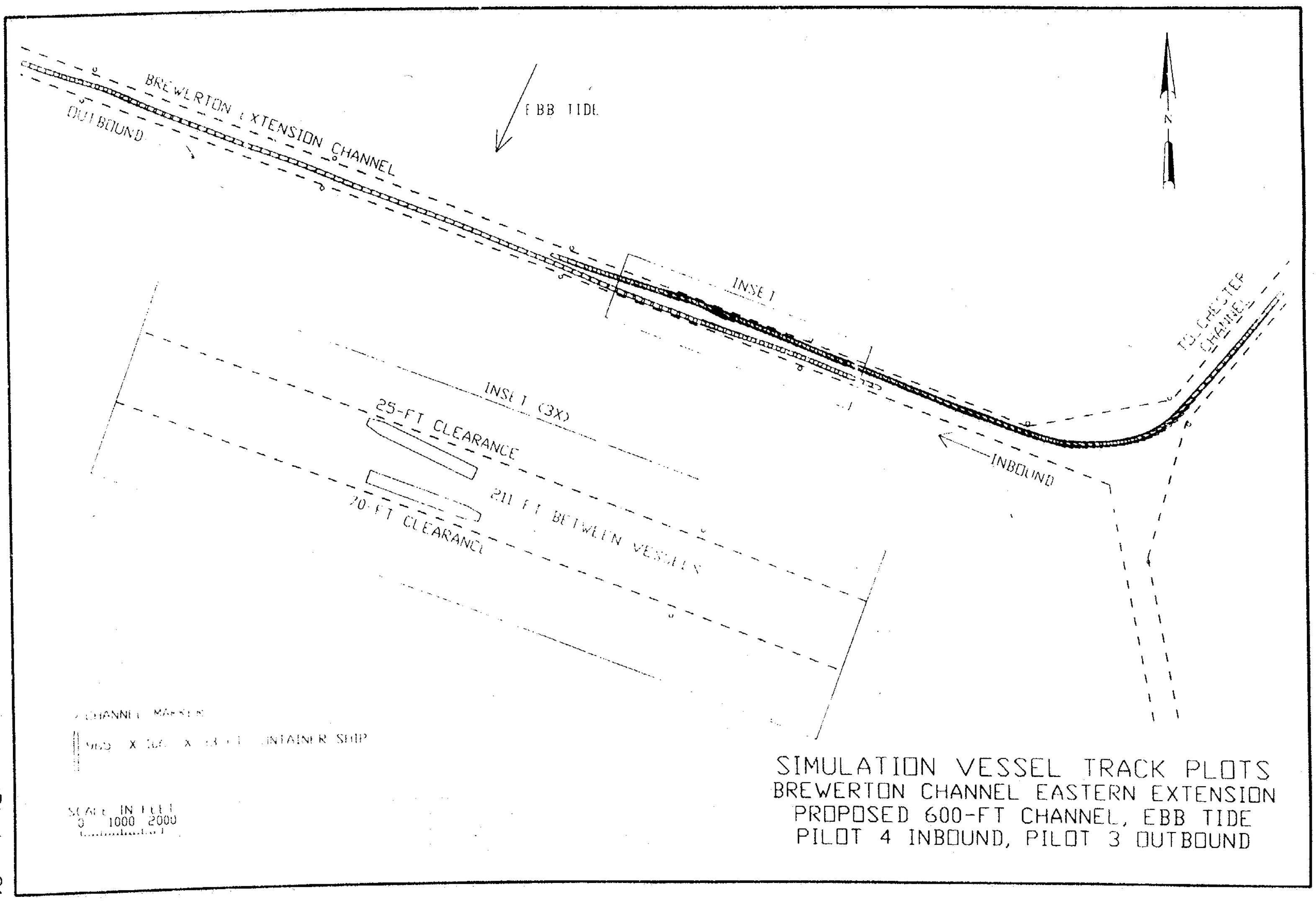


Plate 31

PRELIMINARY

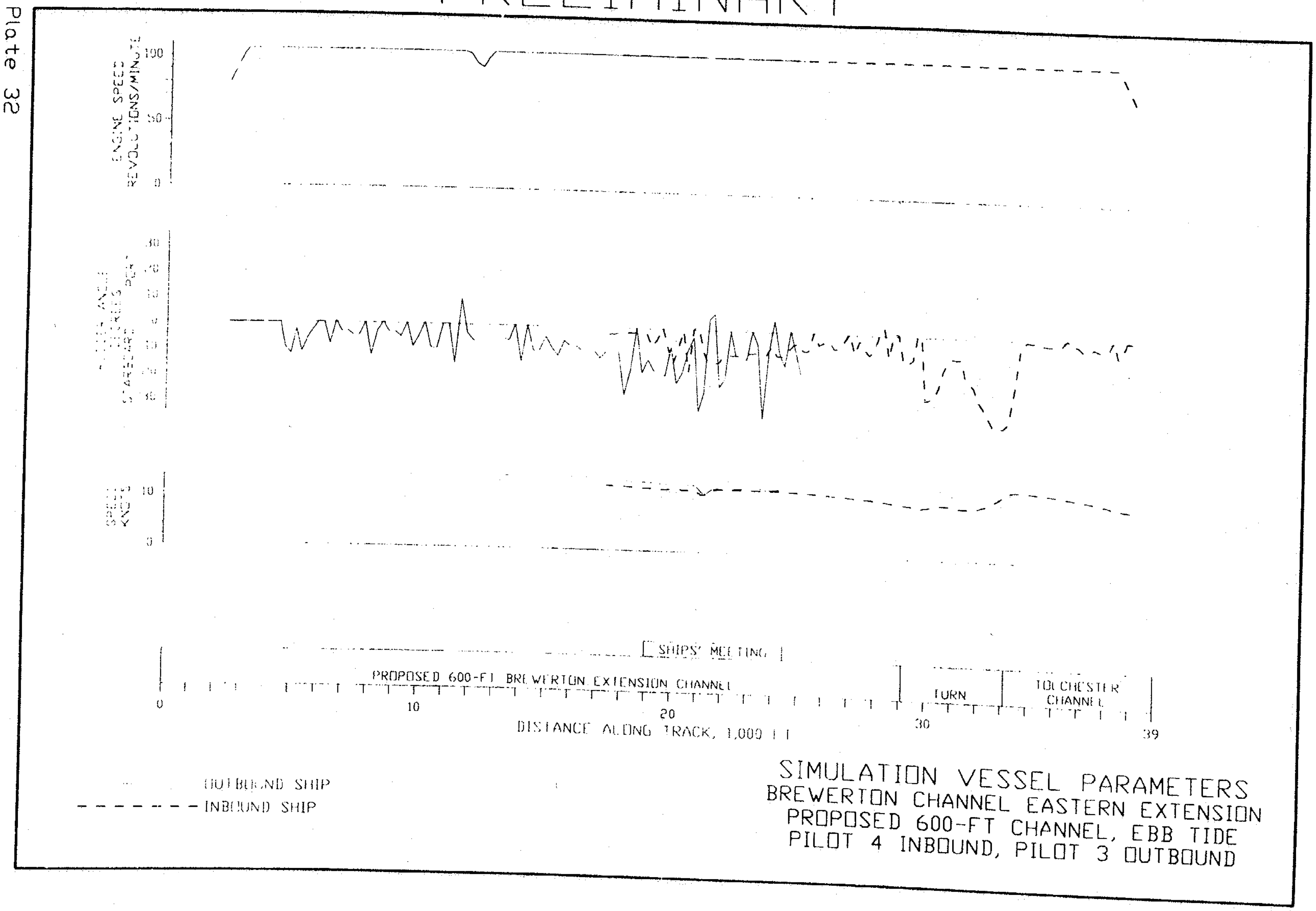


Plate 32

PRELIMINARY

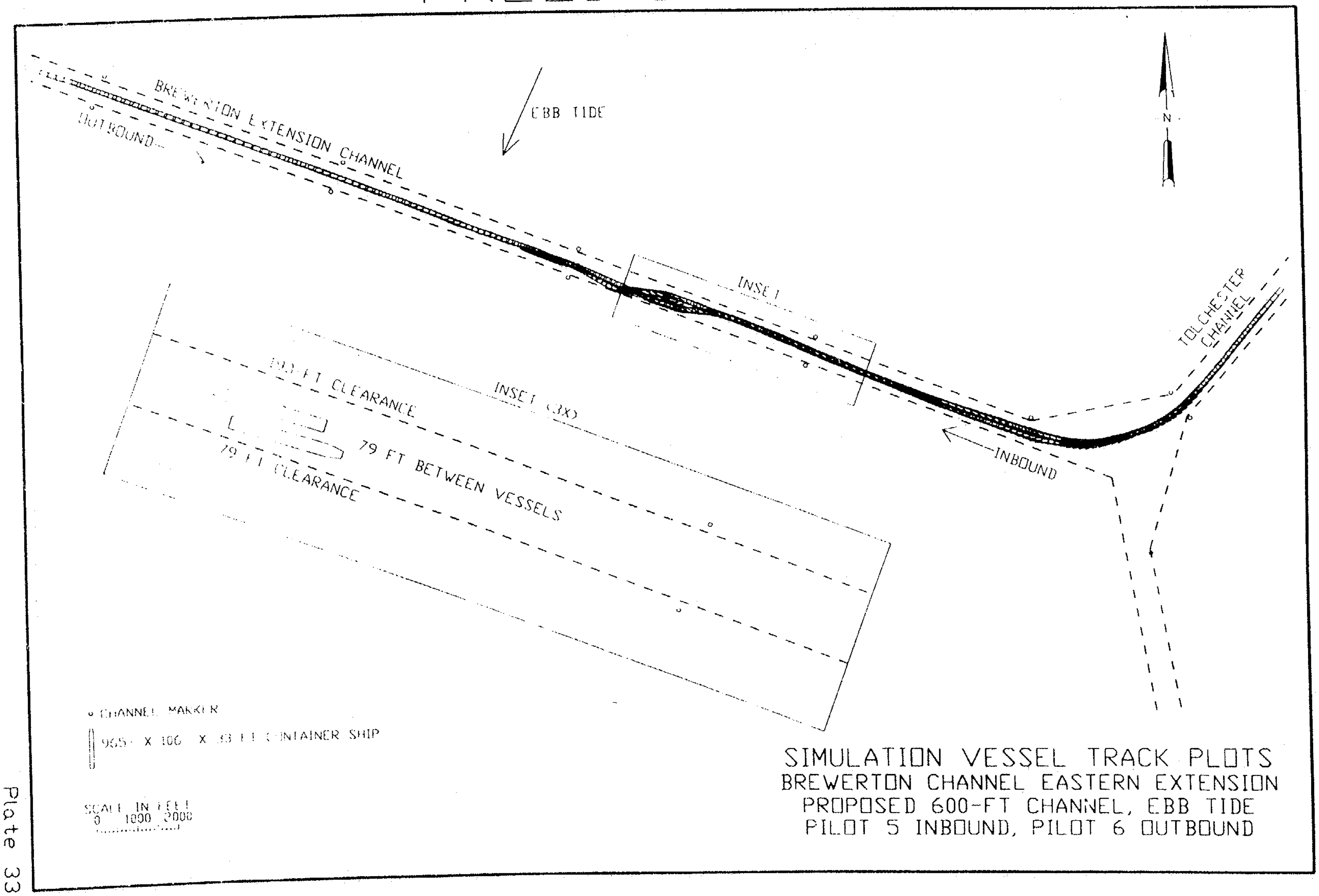


Plate 33

PRELIMINARY

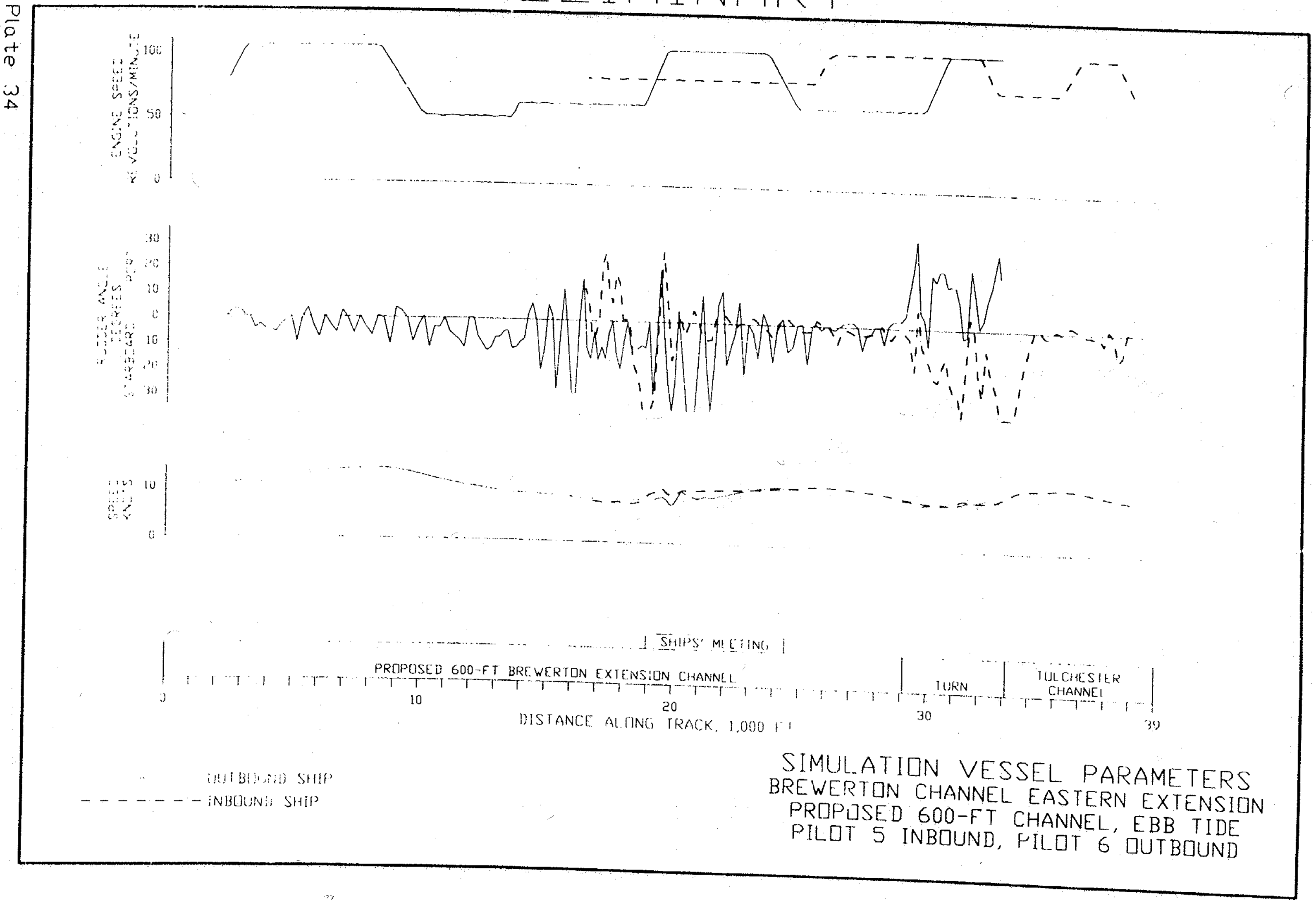
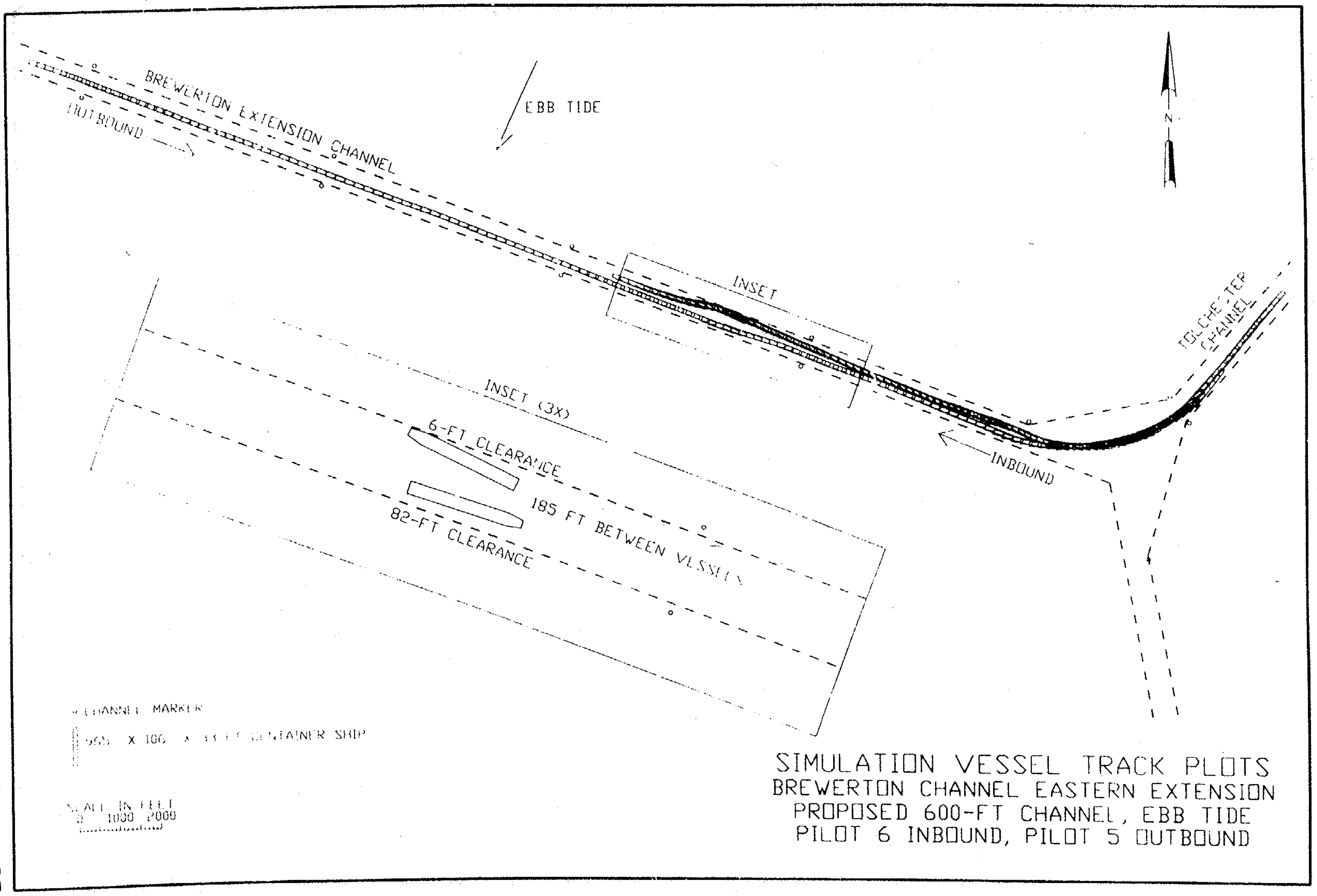


Plate 34

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

PRELIMINARY

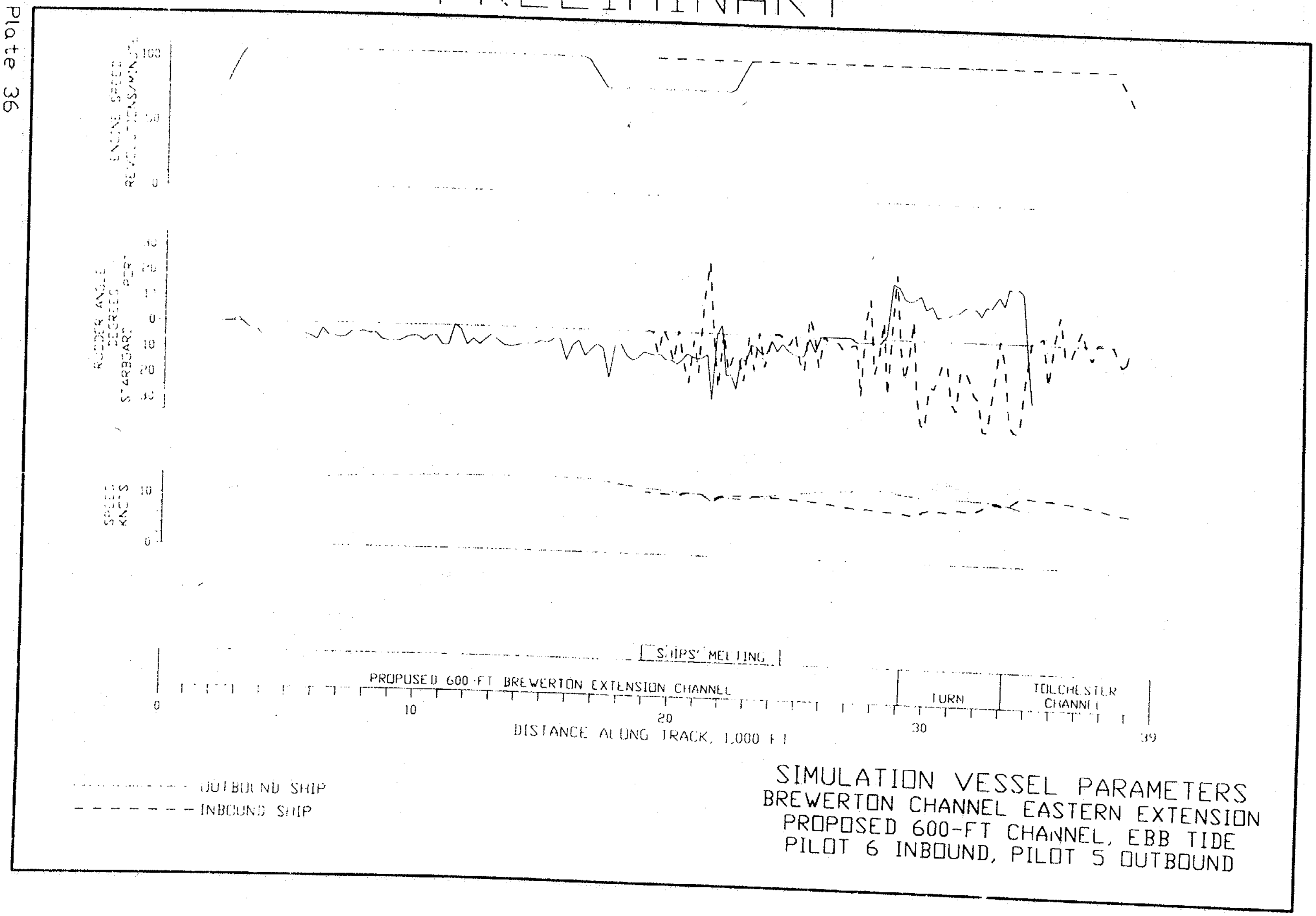
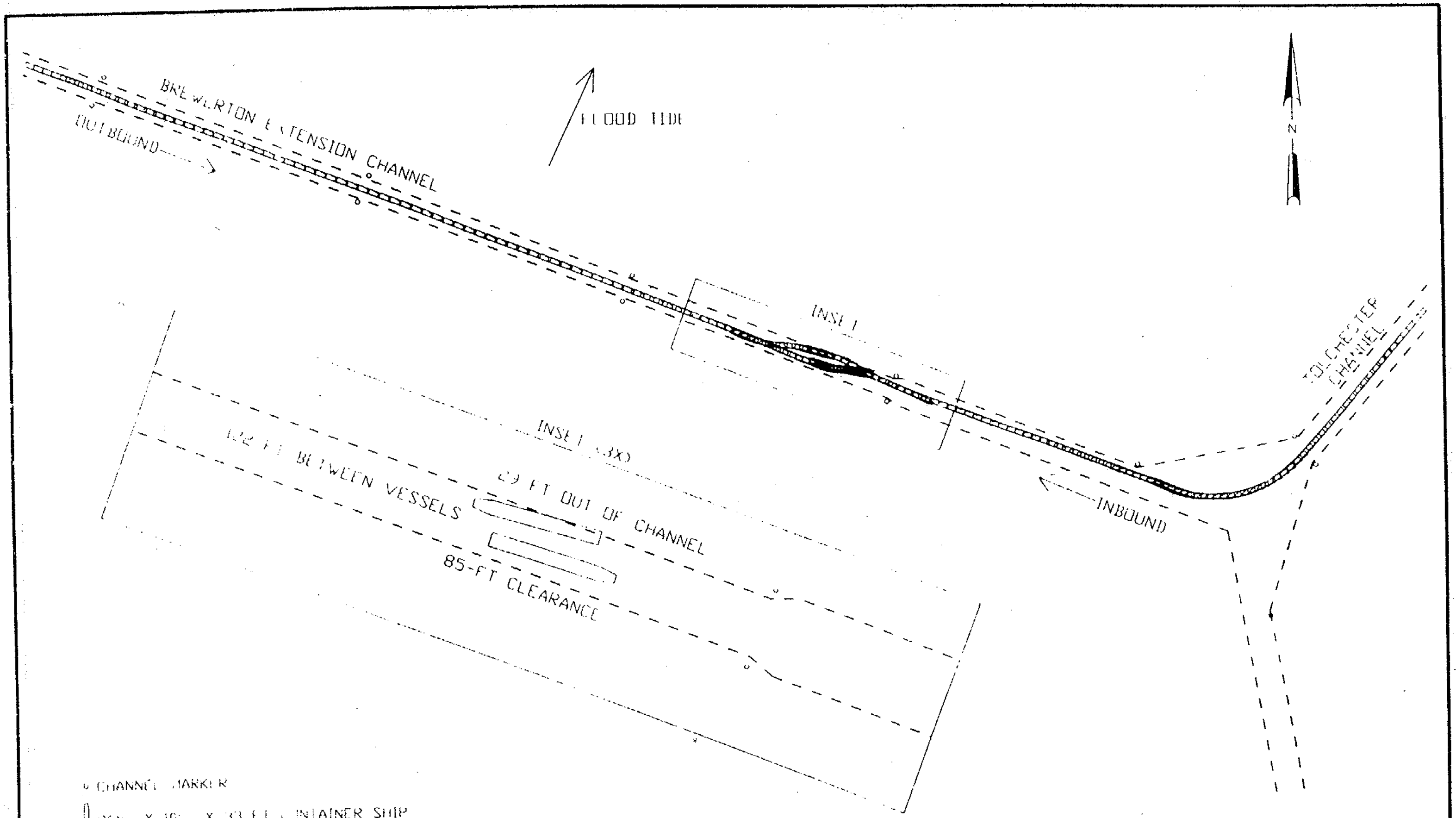


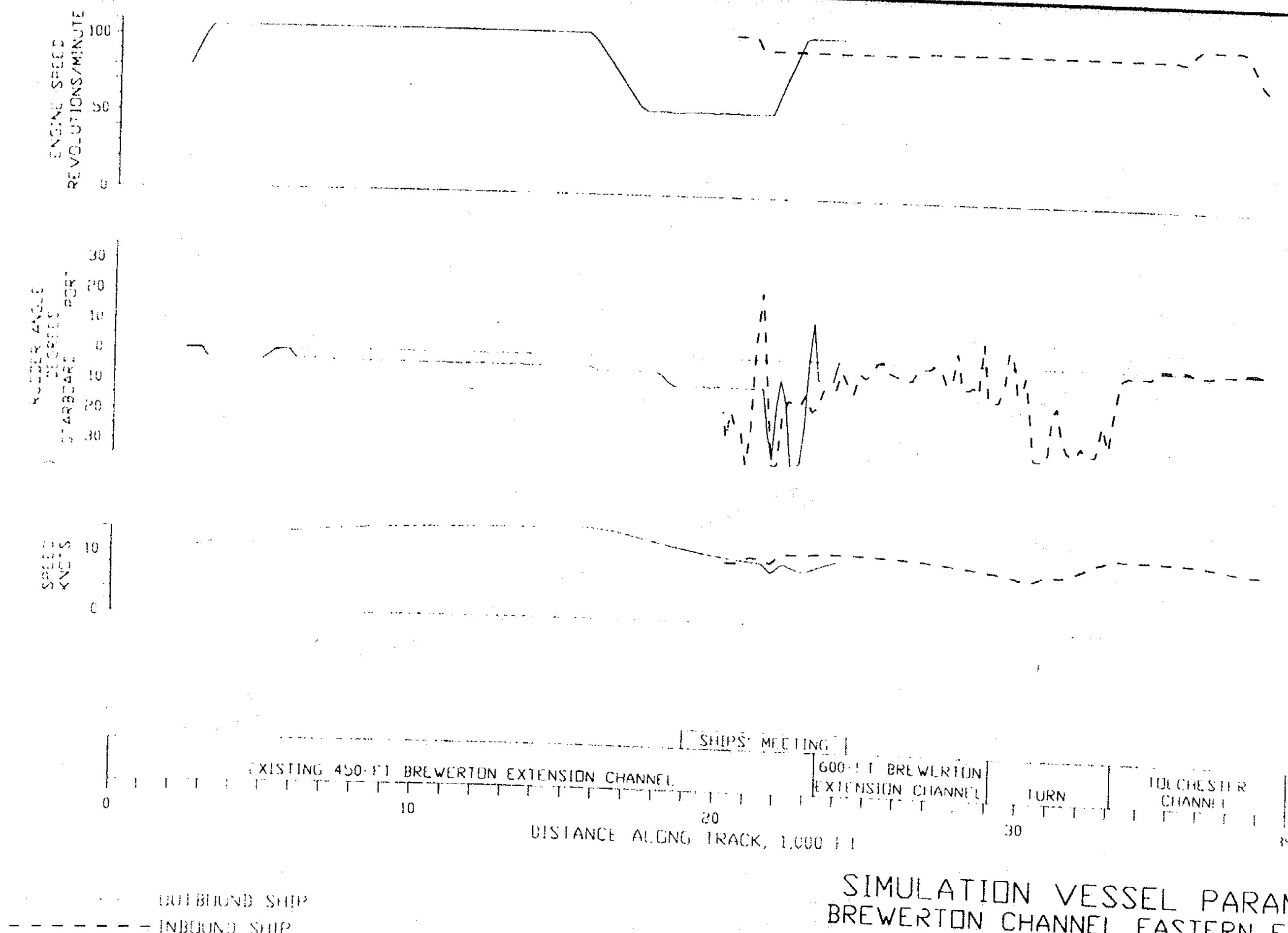
Plate 36

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

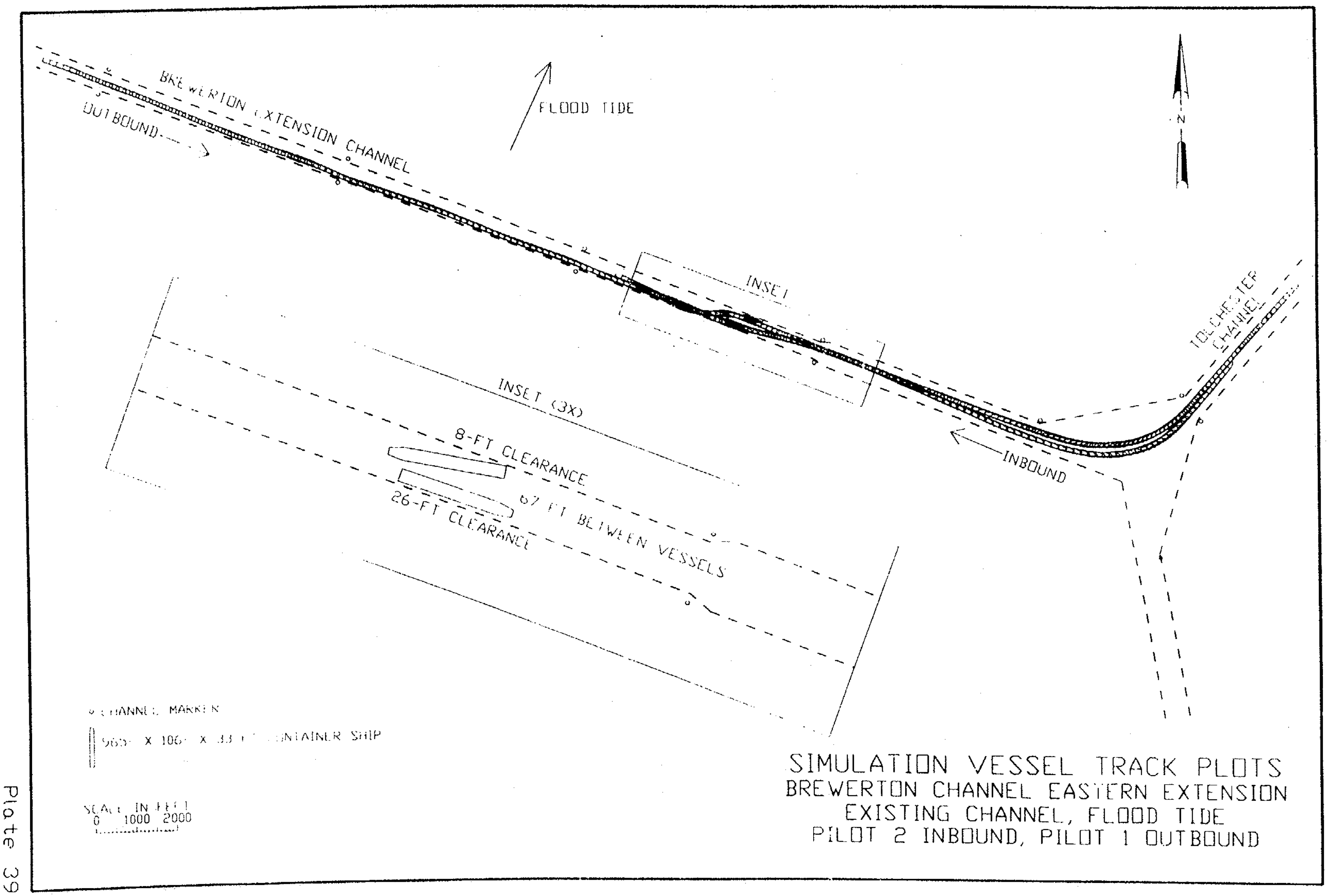
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

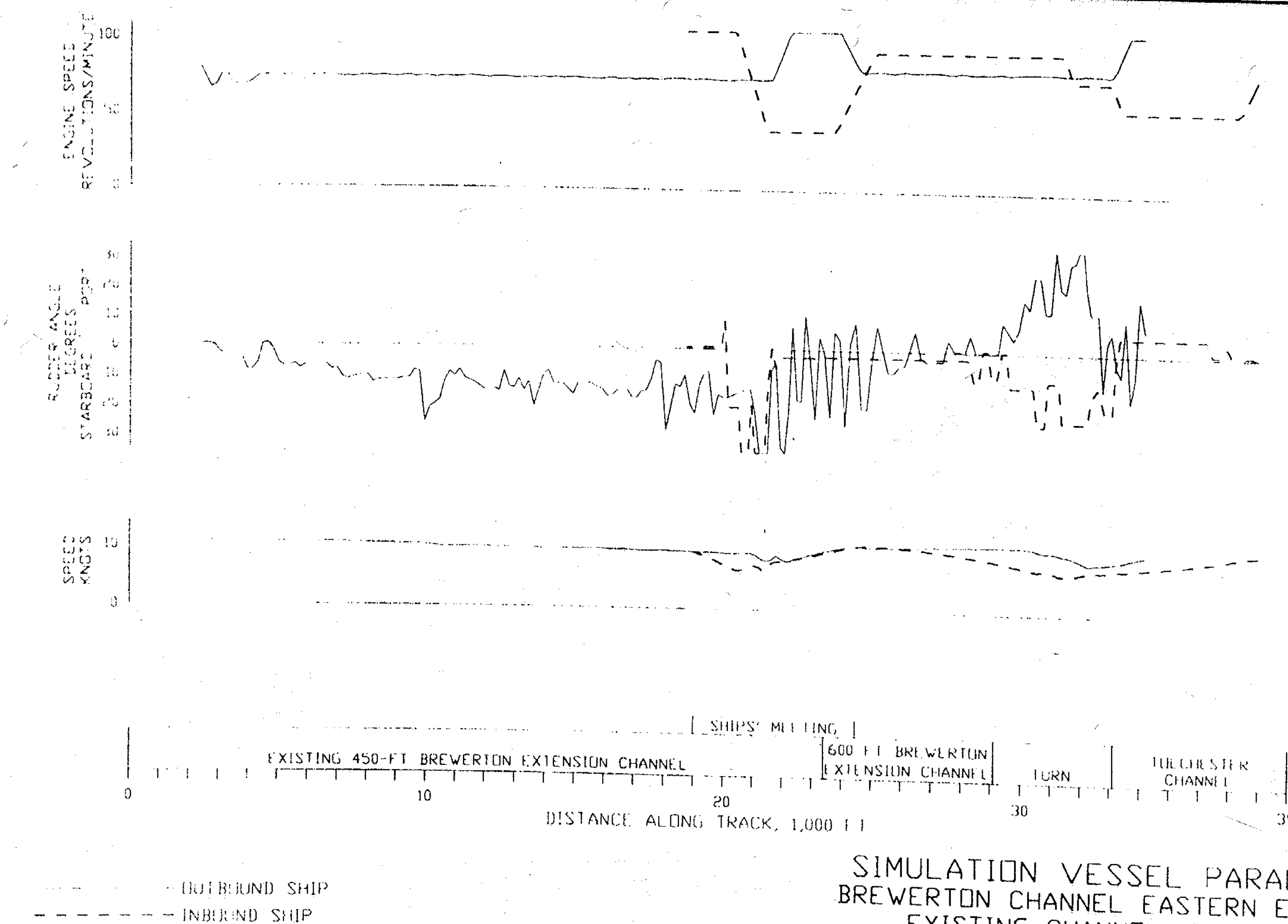
Plate 38

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

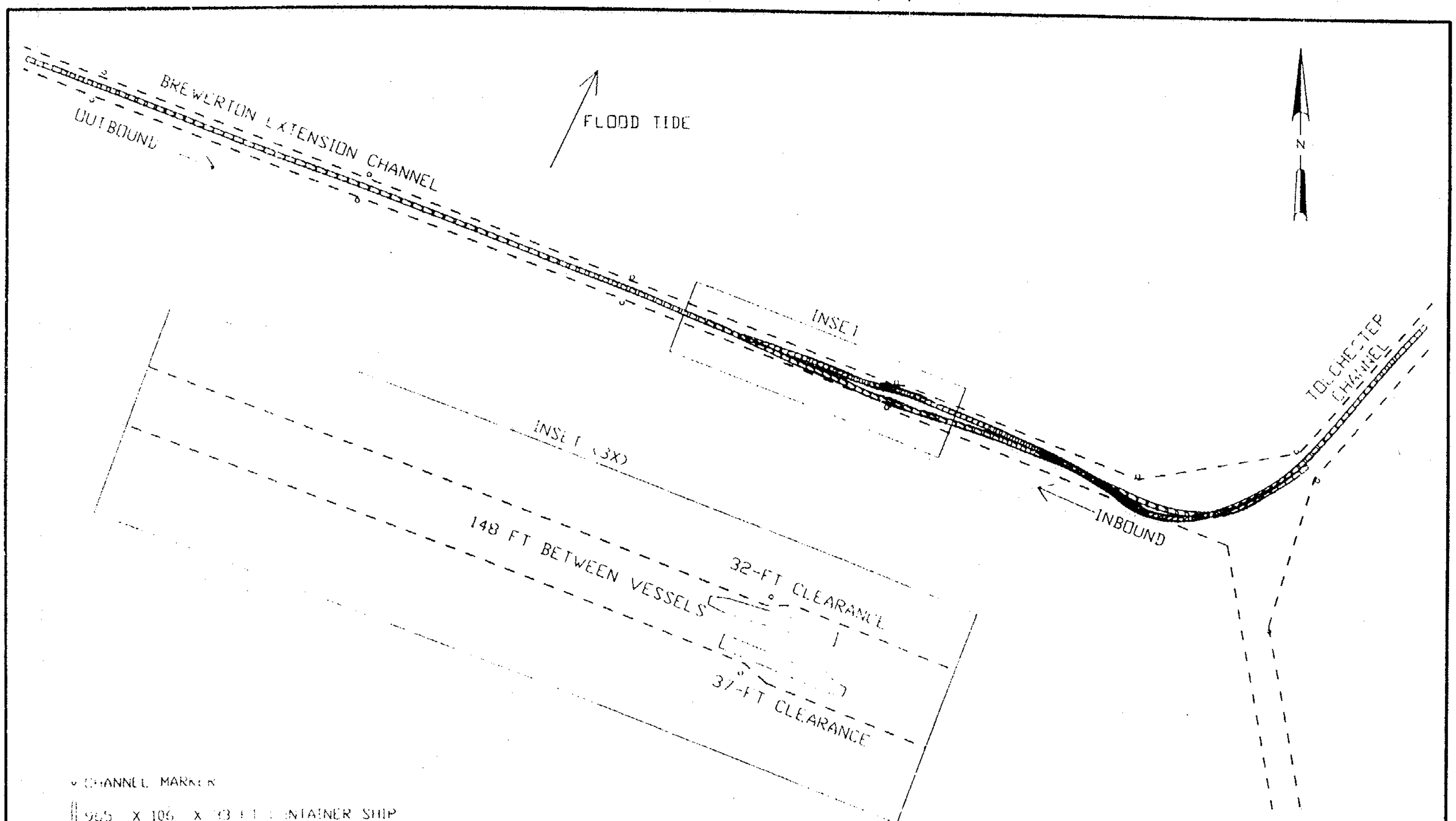
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 40

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY

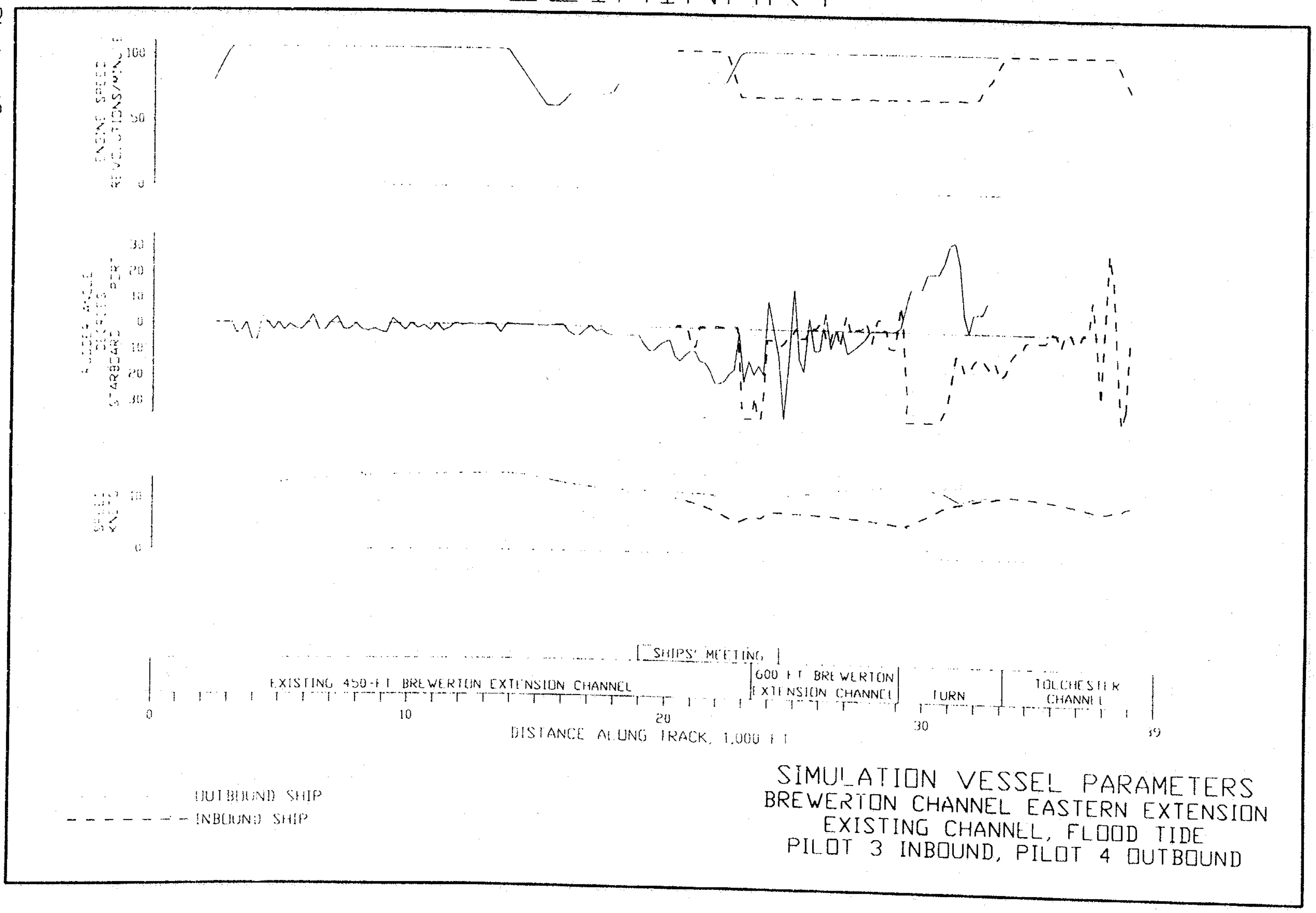


Plate 42

PRELIMINARY

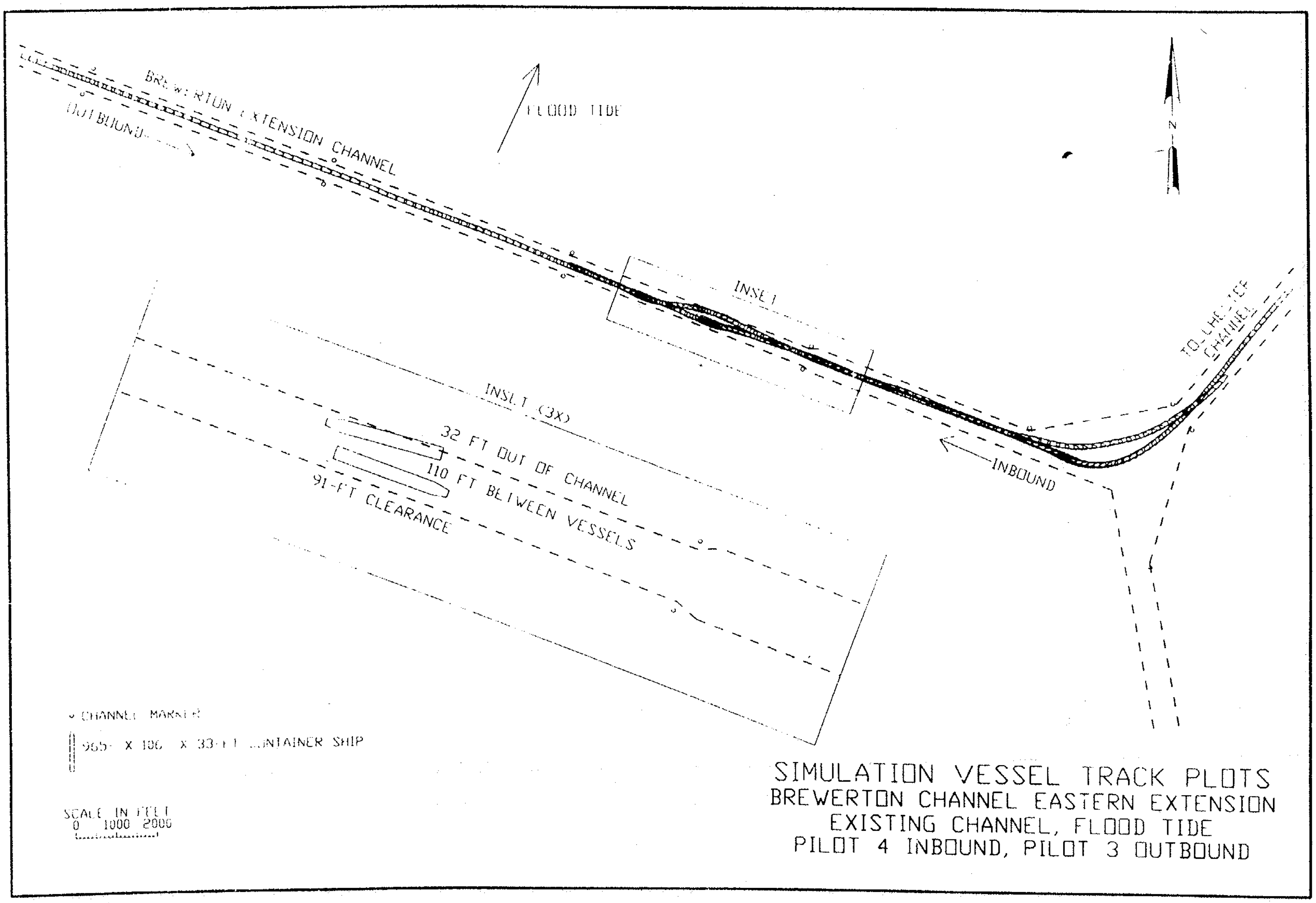
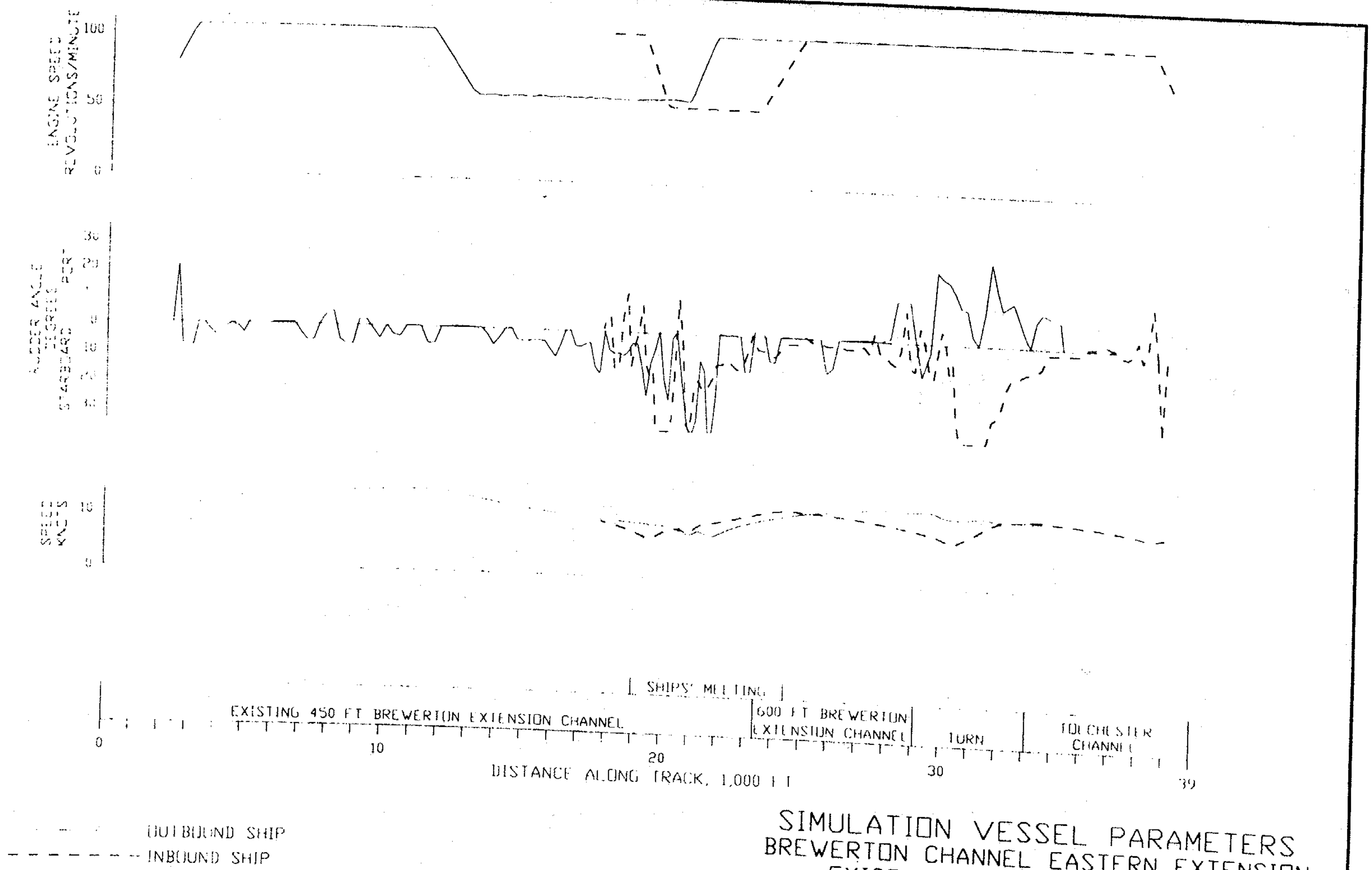


Plate 43

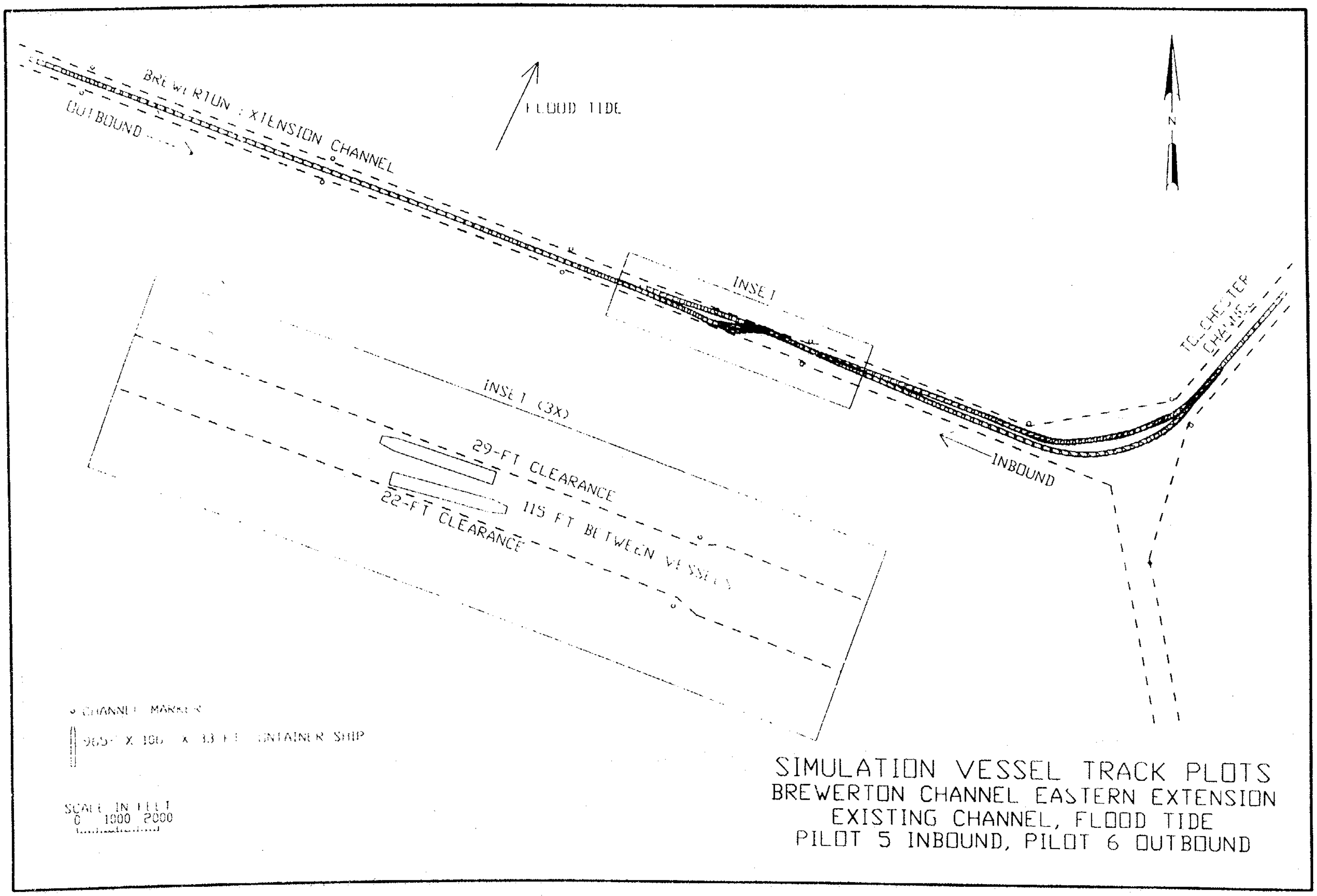
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

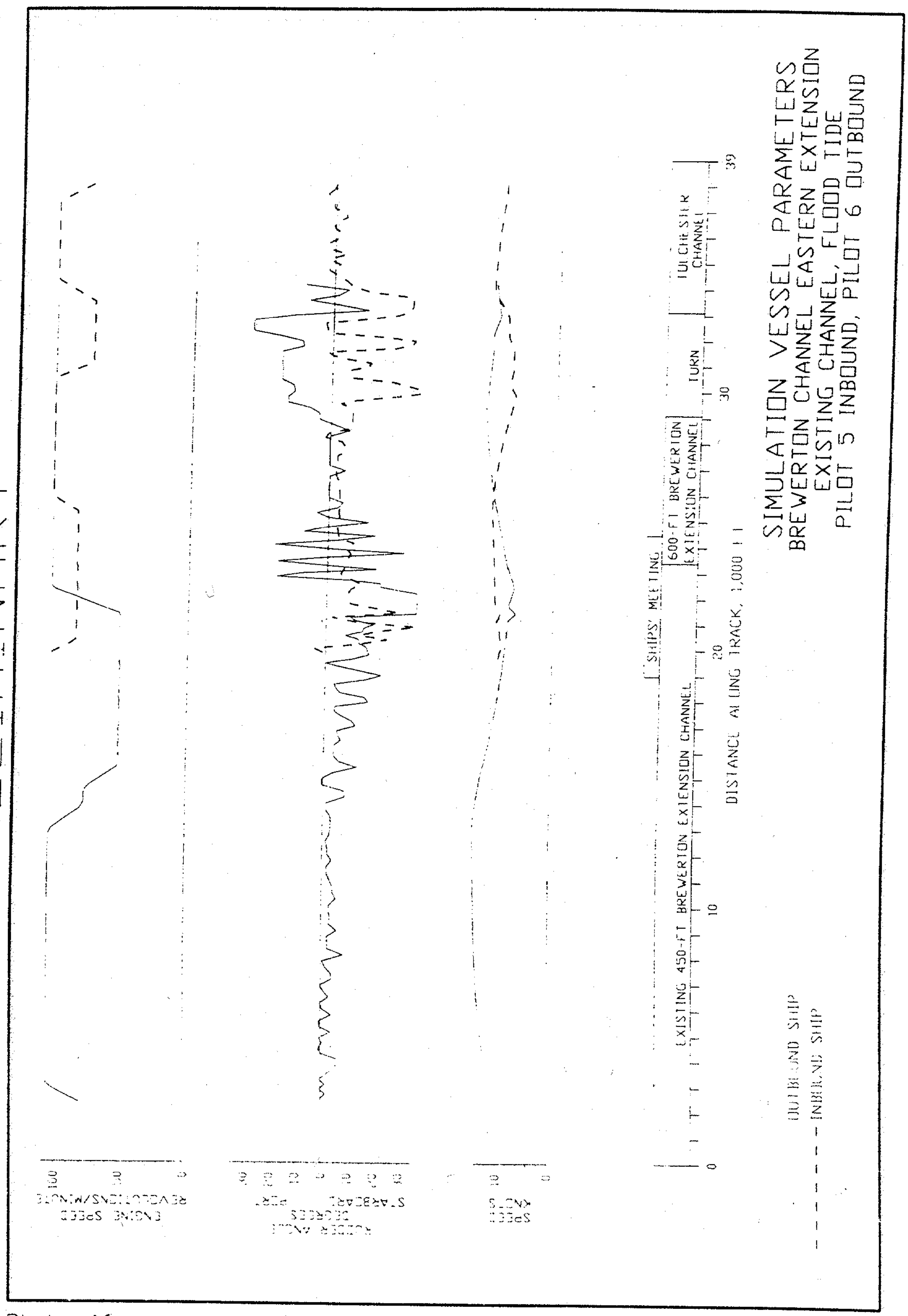
Plate 44

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

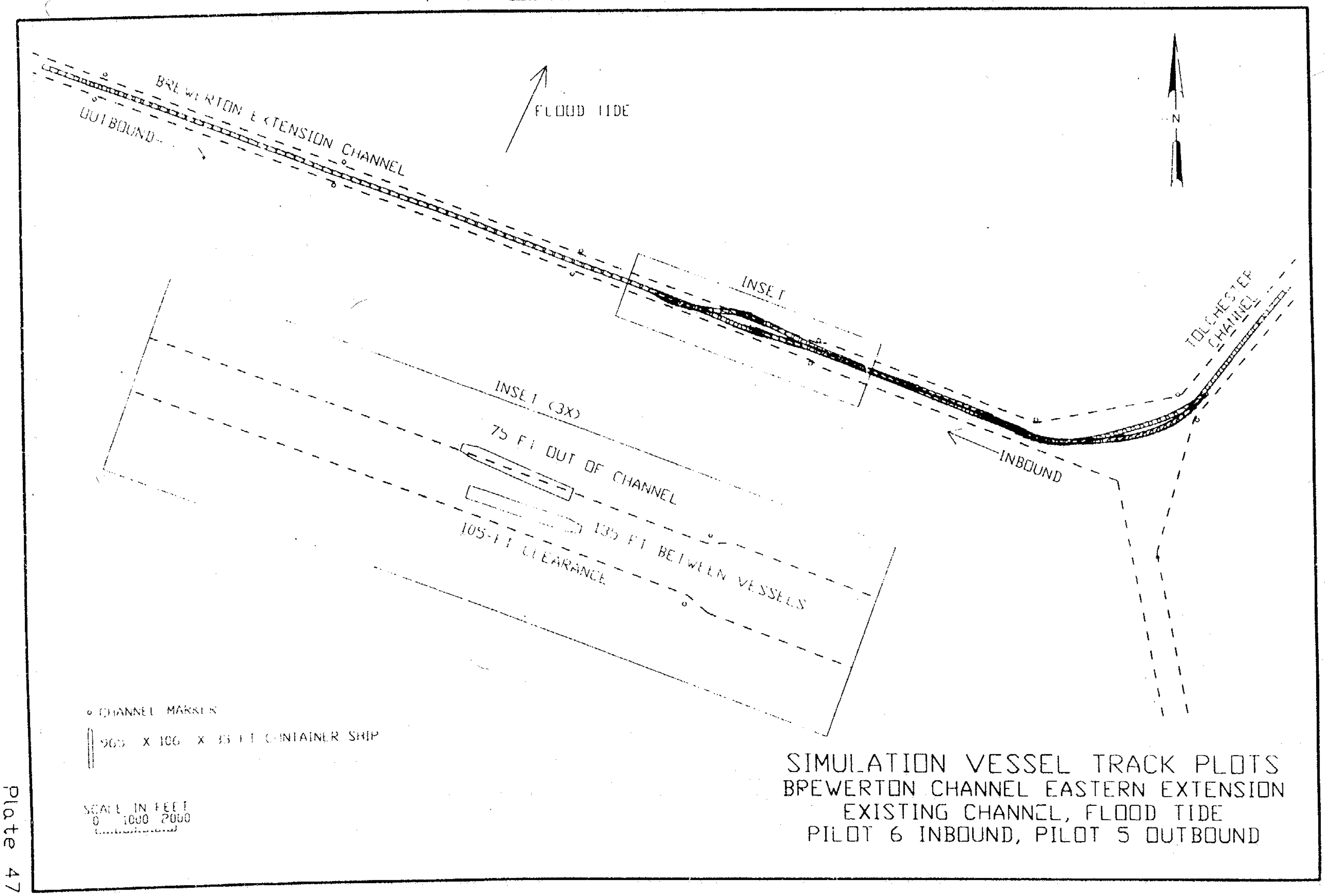
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

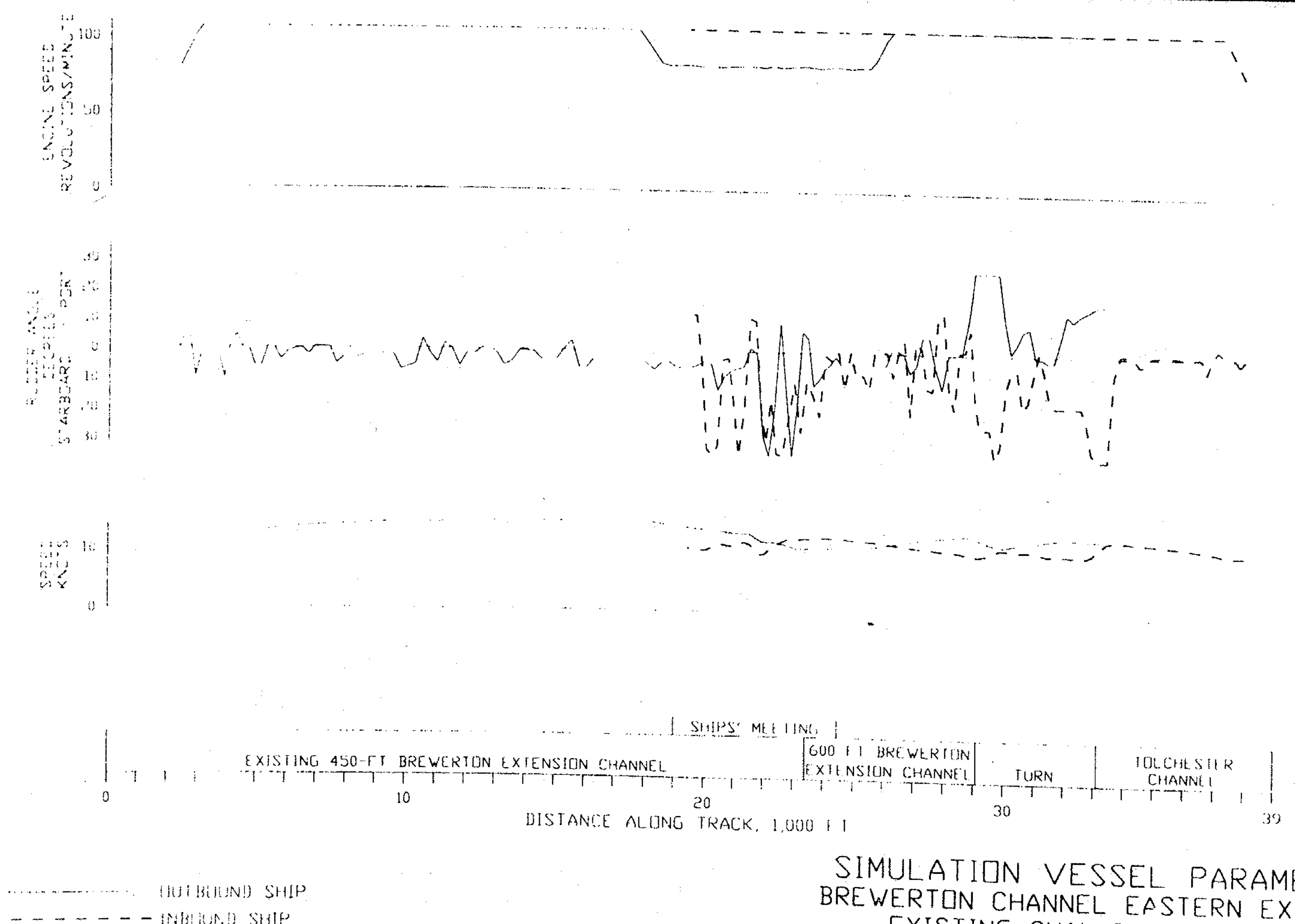
Plate 46

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
EXISTING CHANNEL, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 48

PRELIMINARY

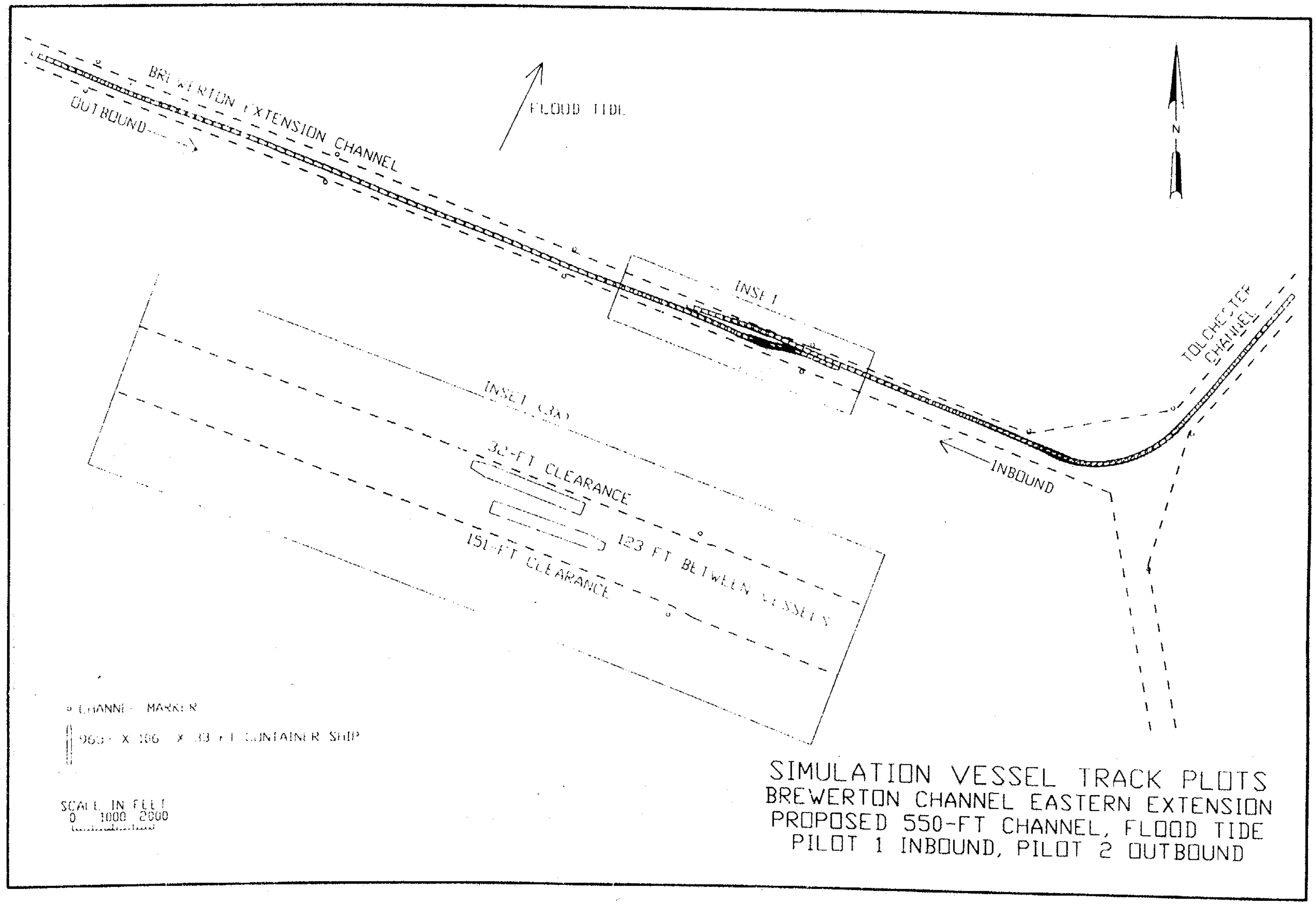
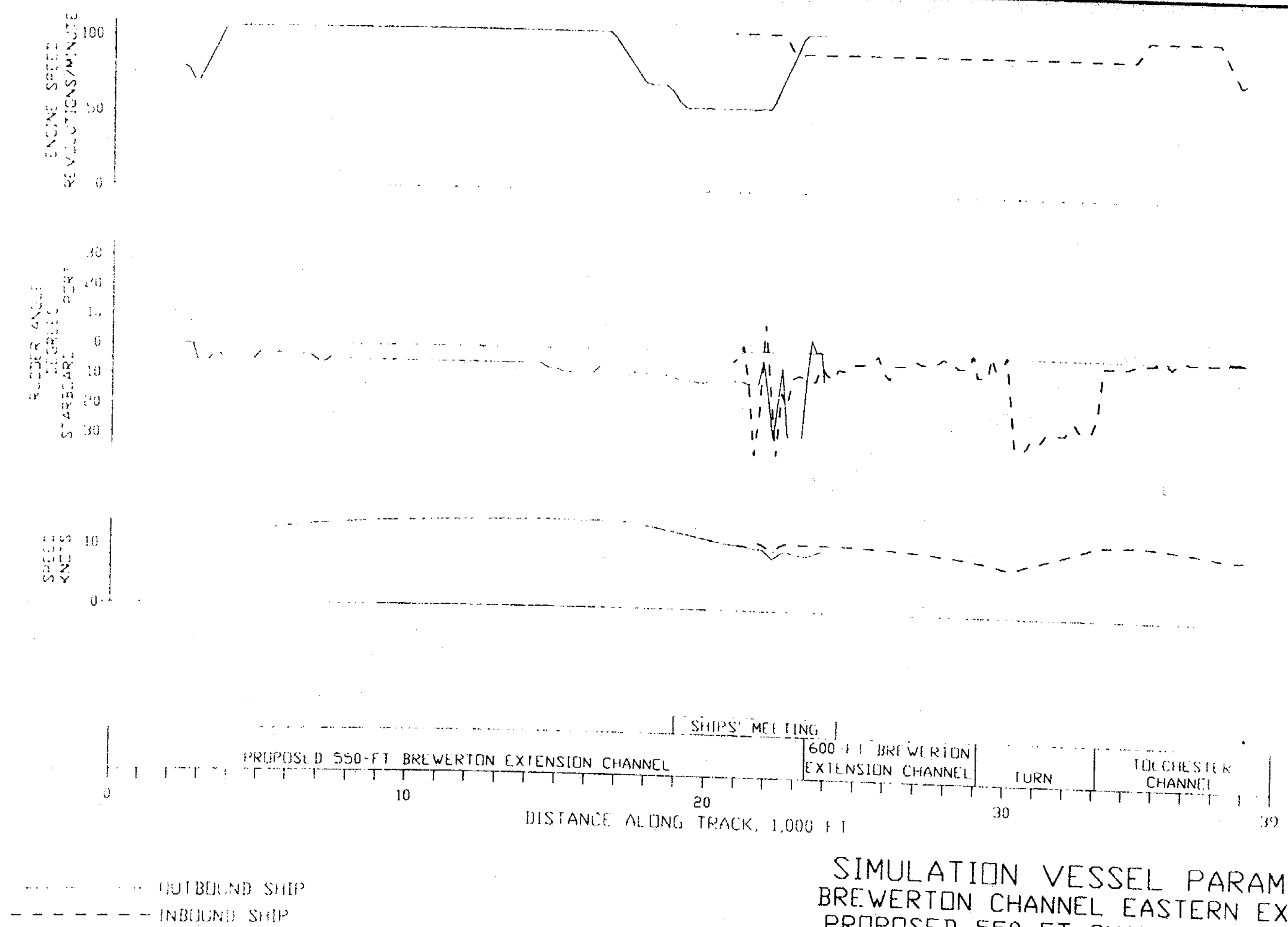


Plate 49

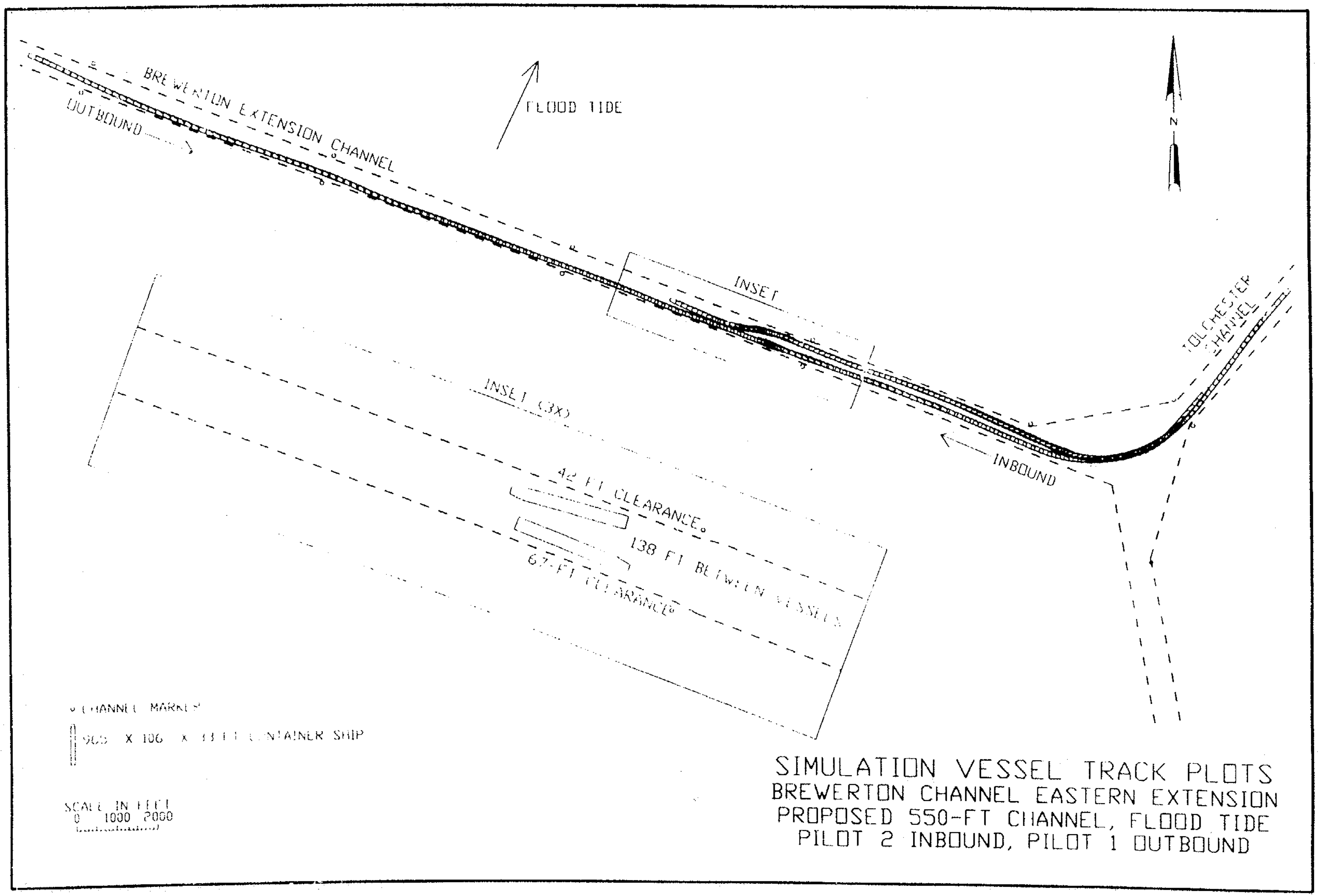
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

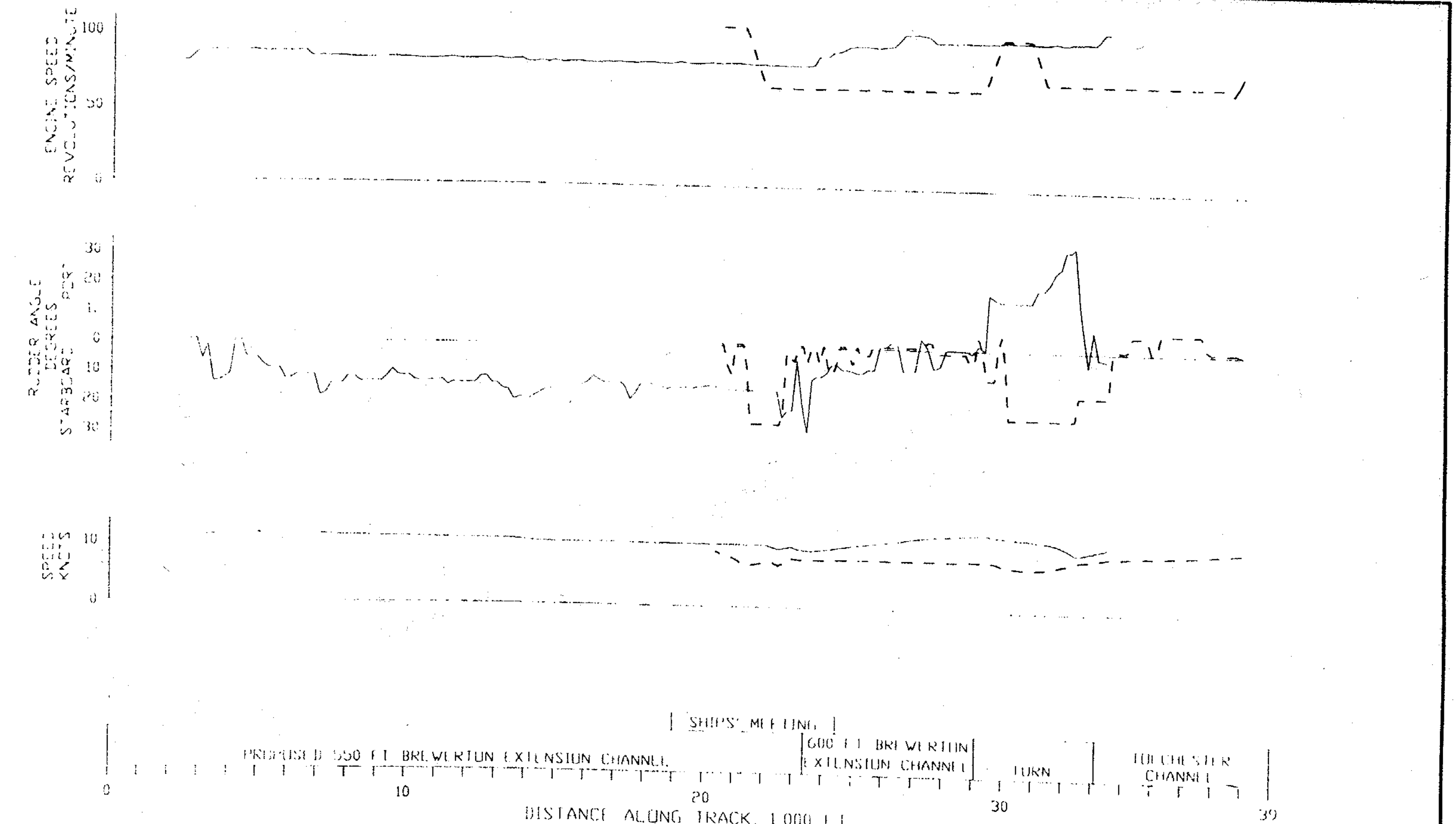
Plate 50

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

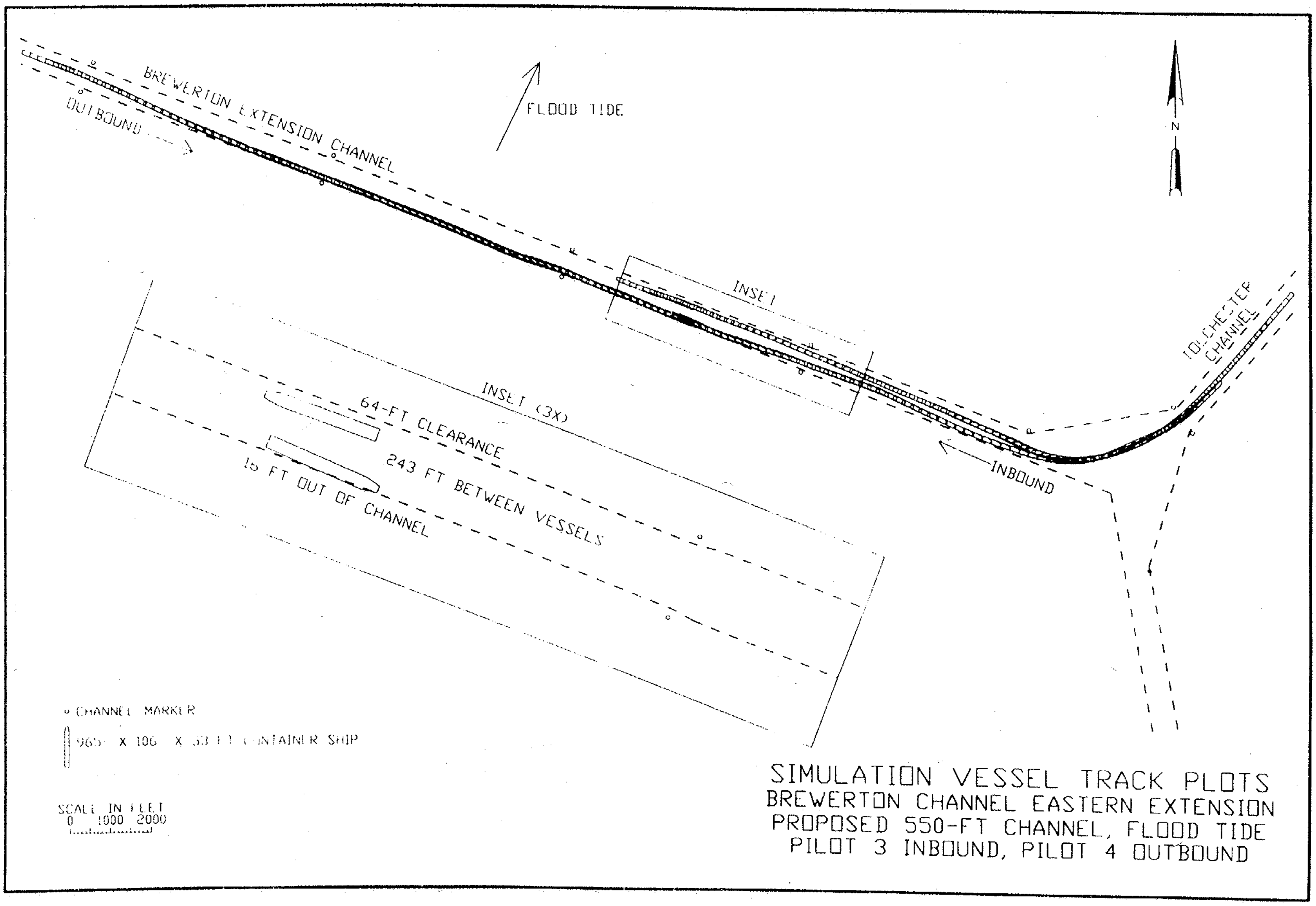
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 52

PRELIMINARY



PRELIMINARY

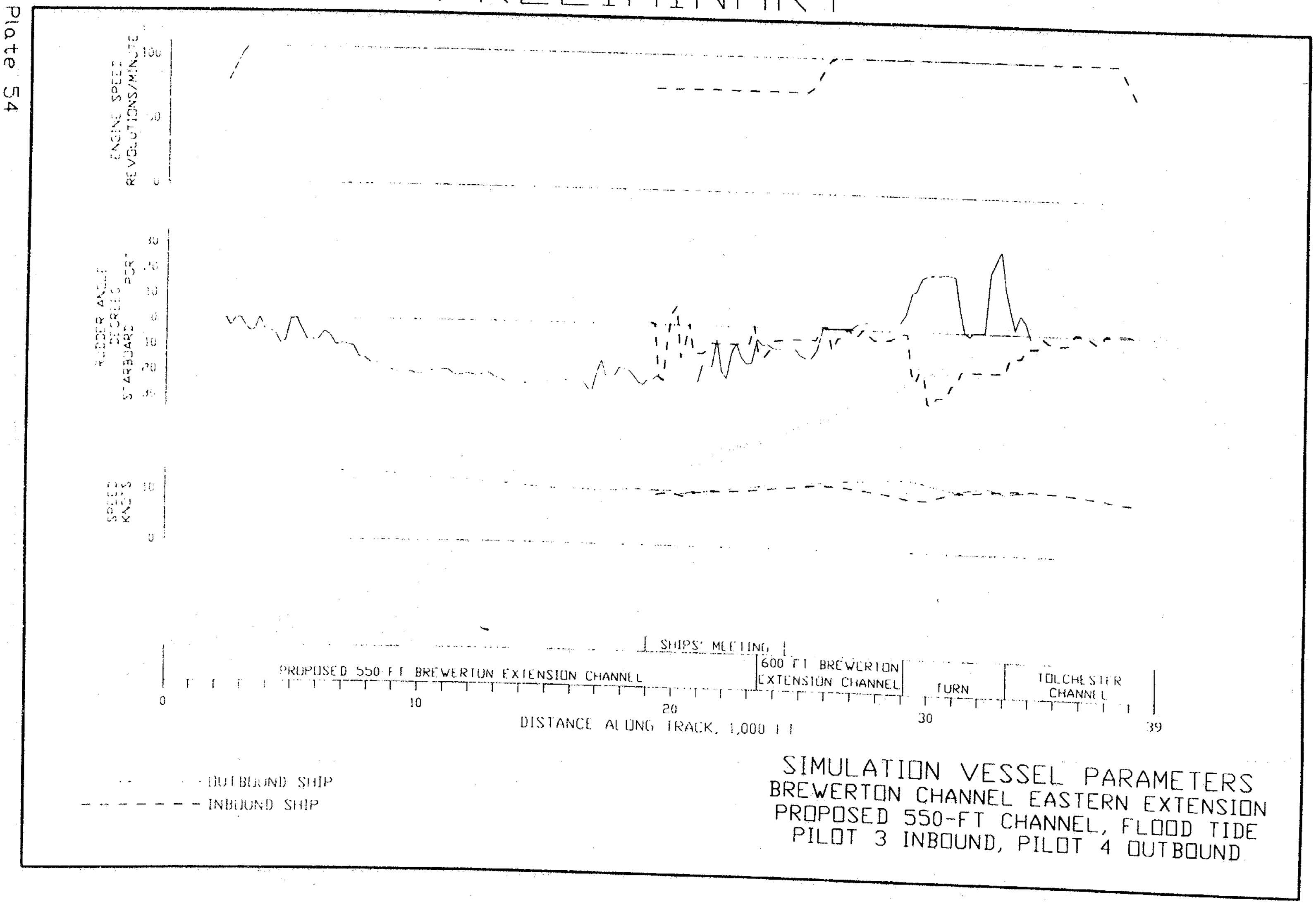
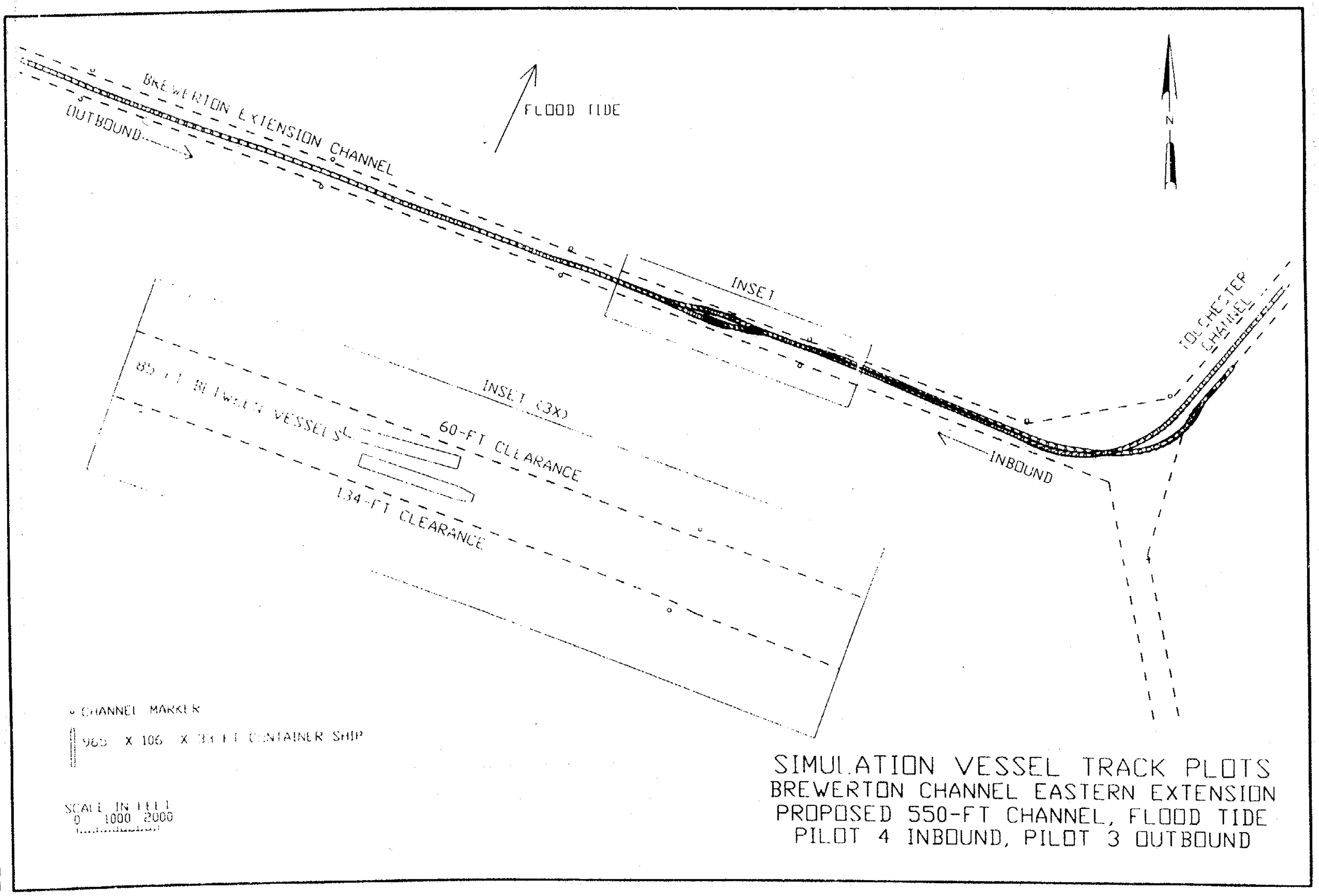


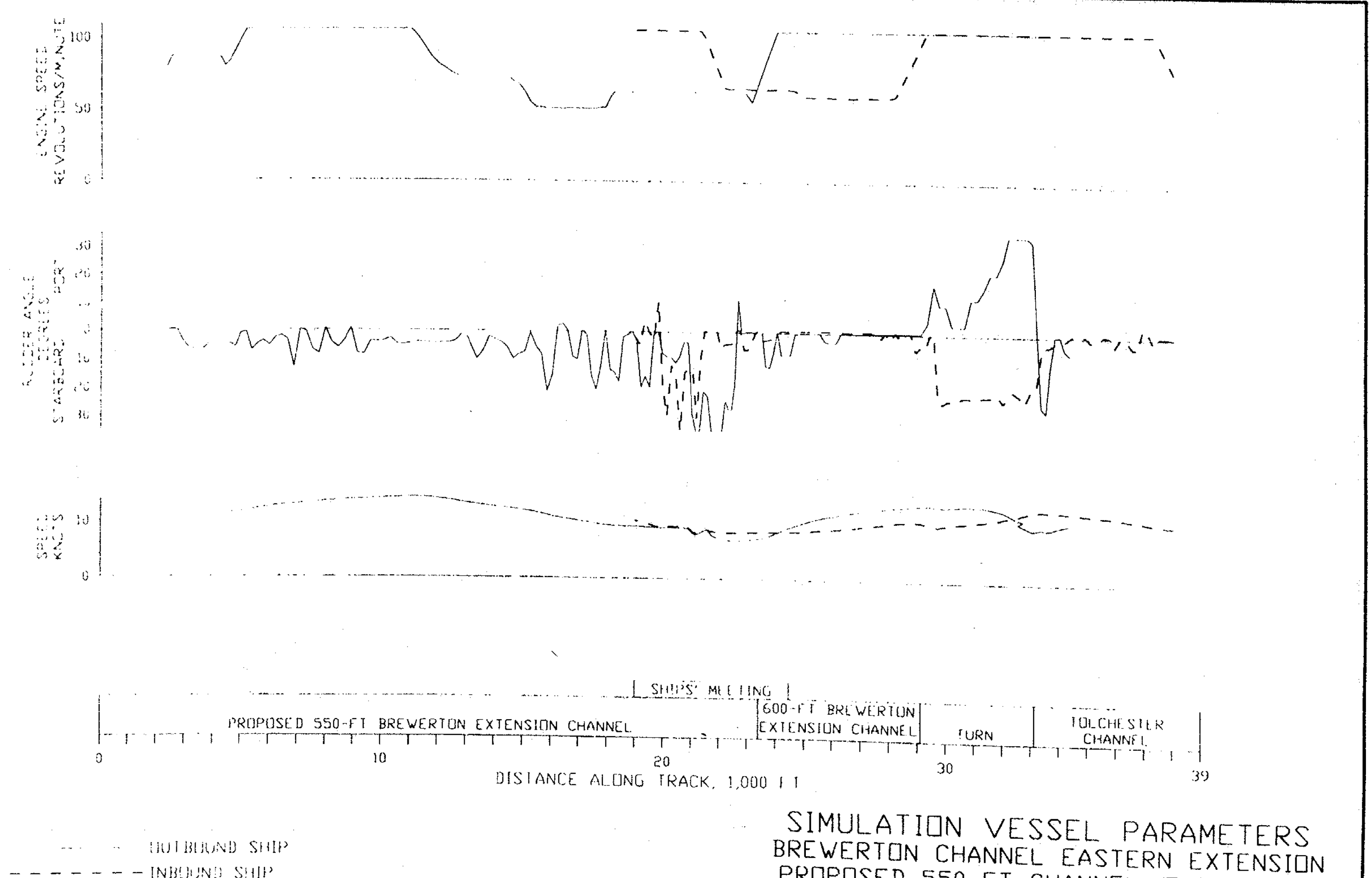
Plate 54

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

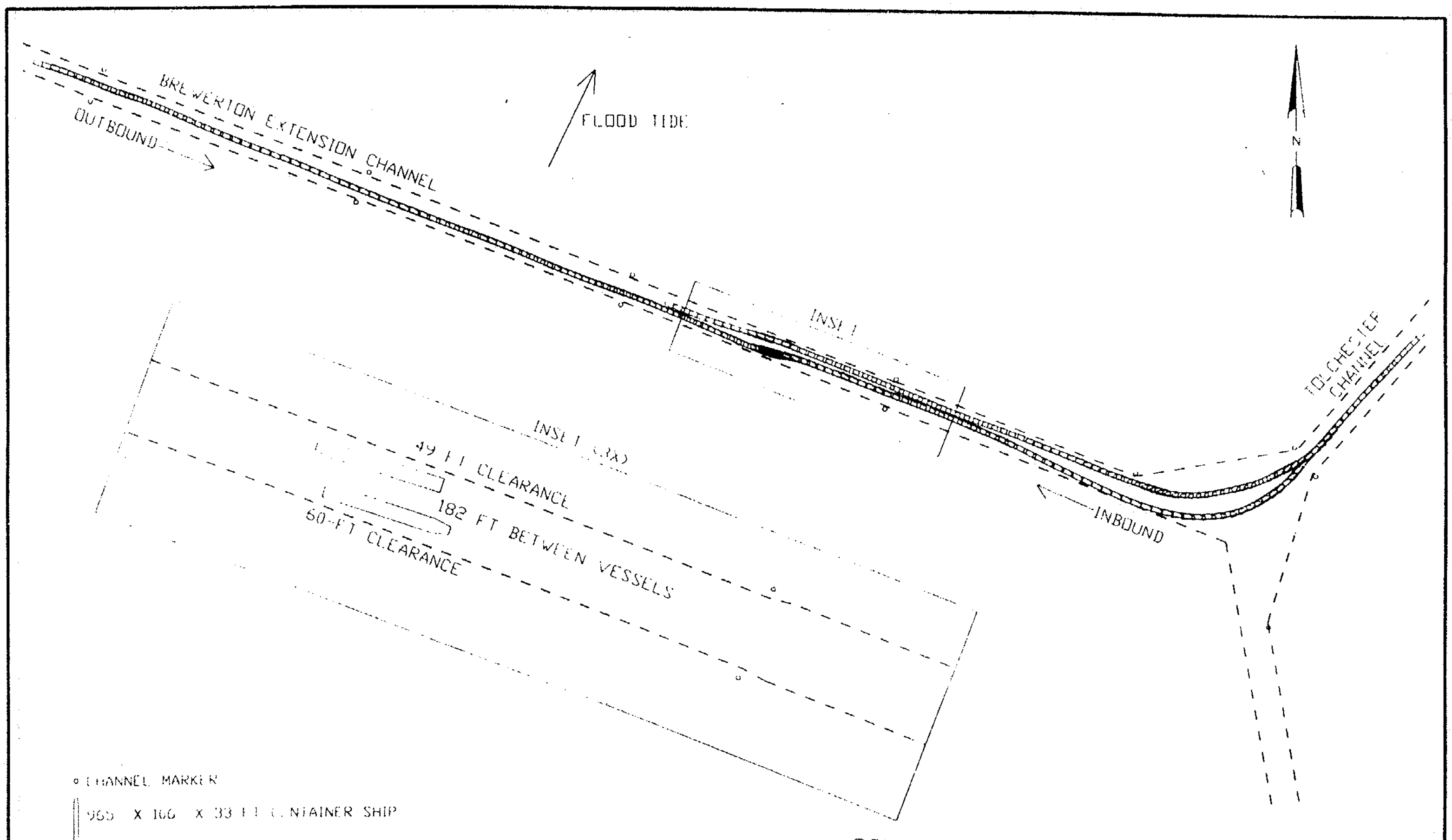
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

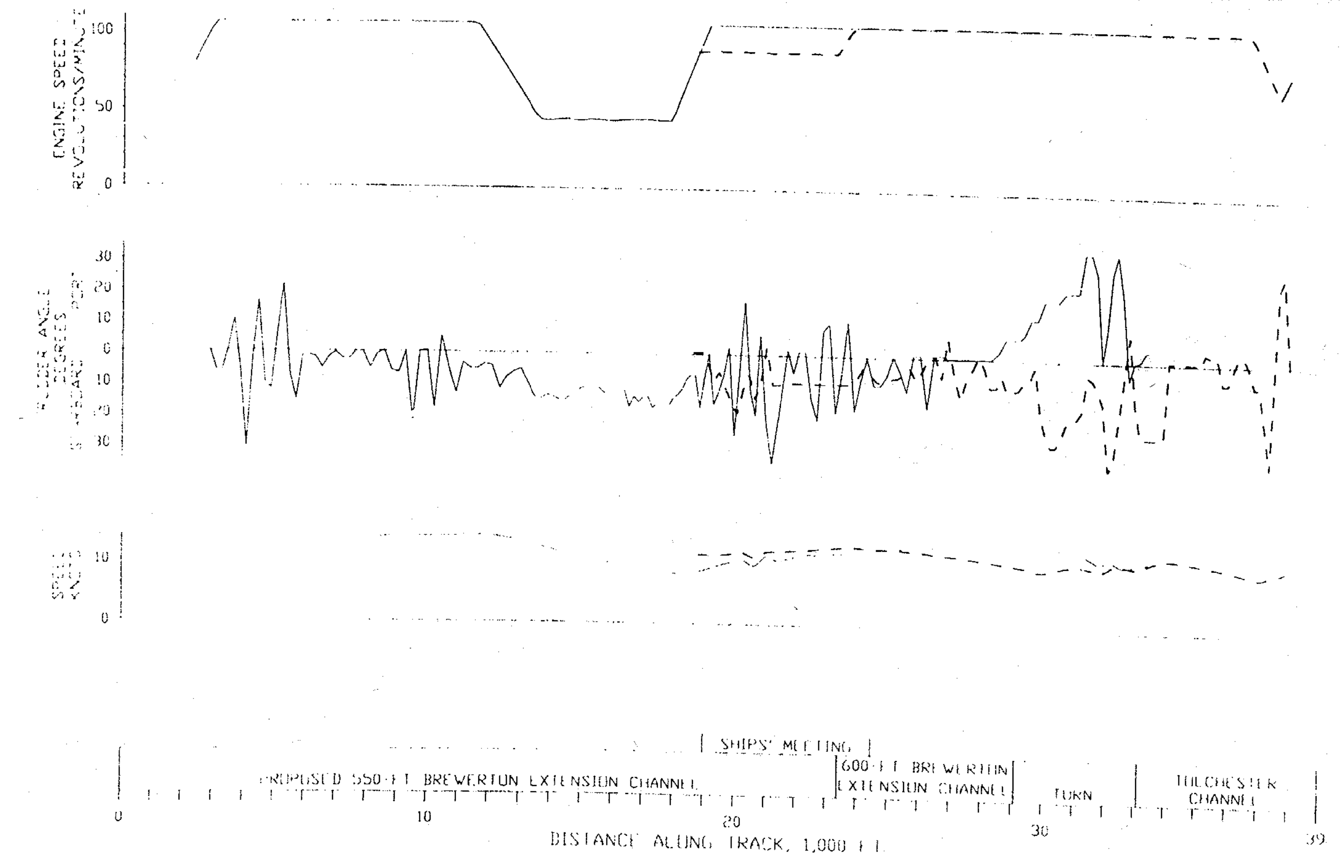
Plate 56

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

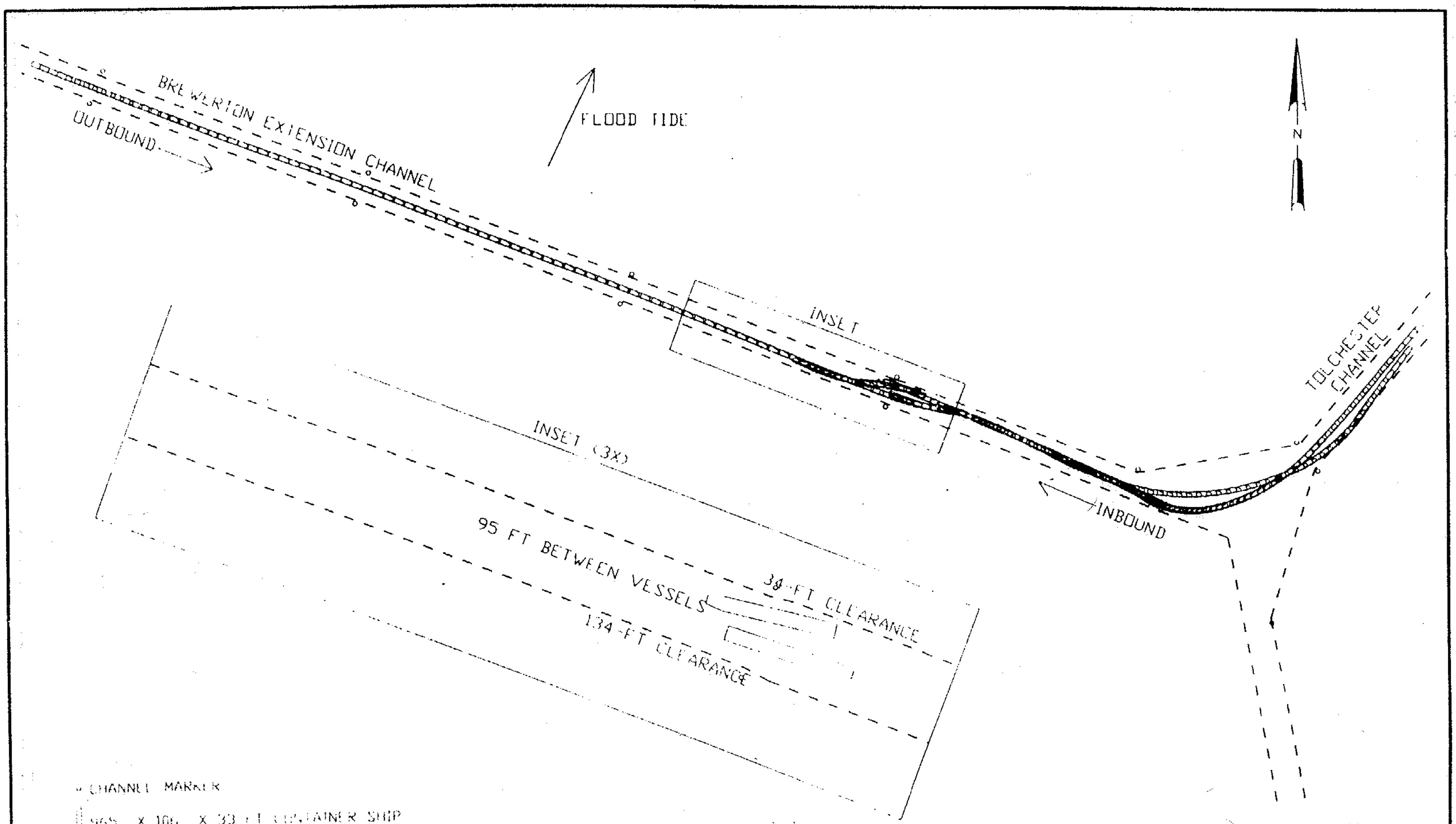
PRELIMINARY



OUTBOUND SHIP
INBOUND SHIP

SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

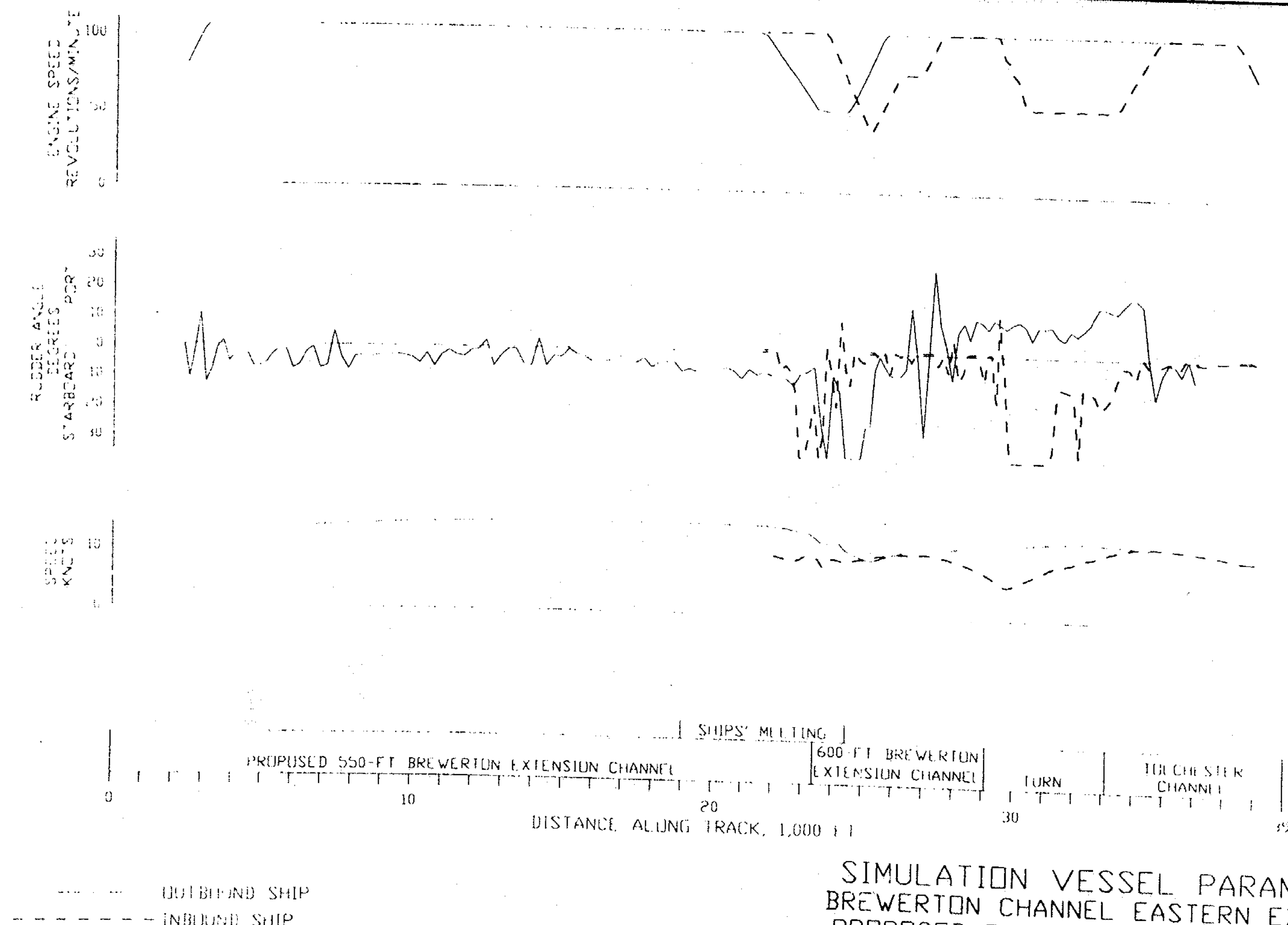
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 59

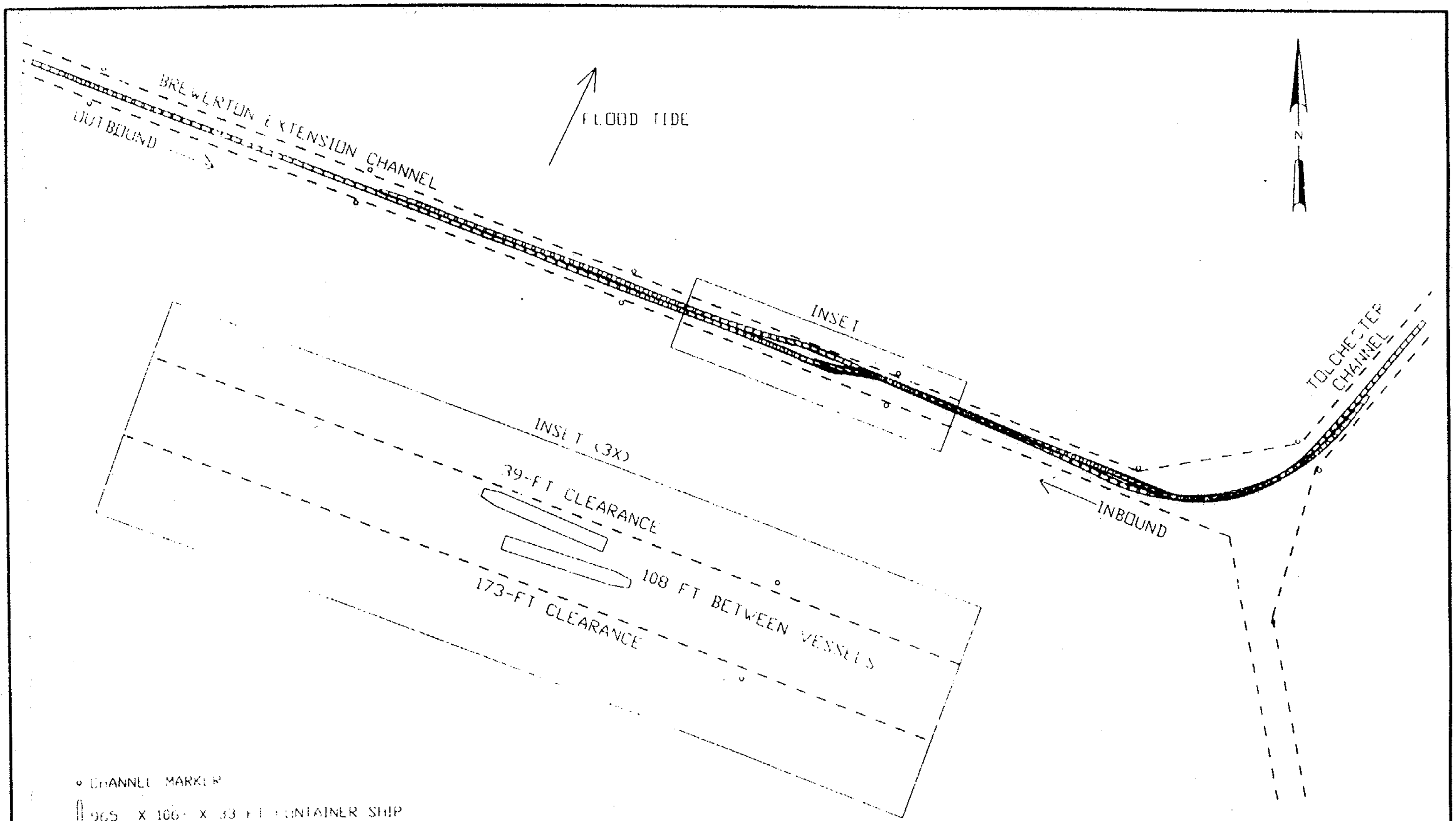
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 550-FT CHANNEL, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

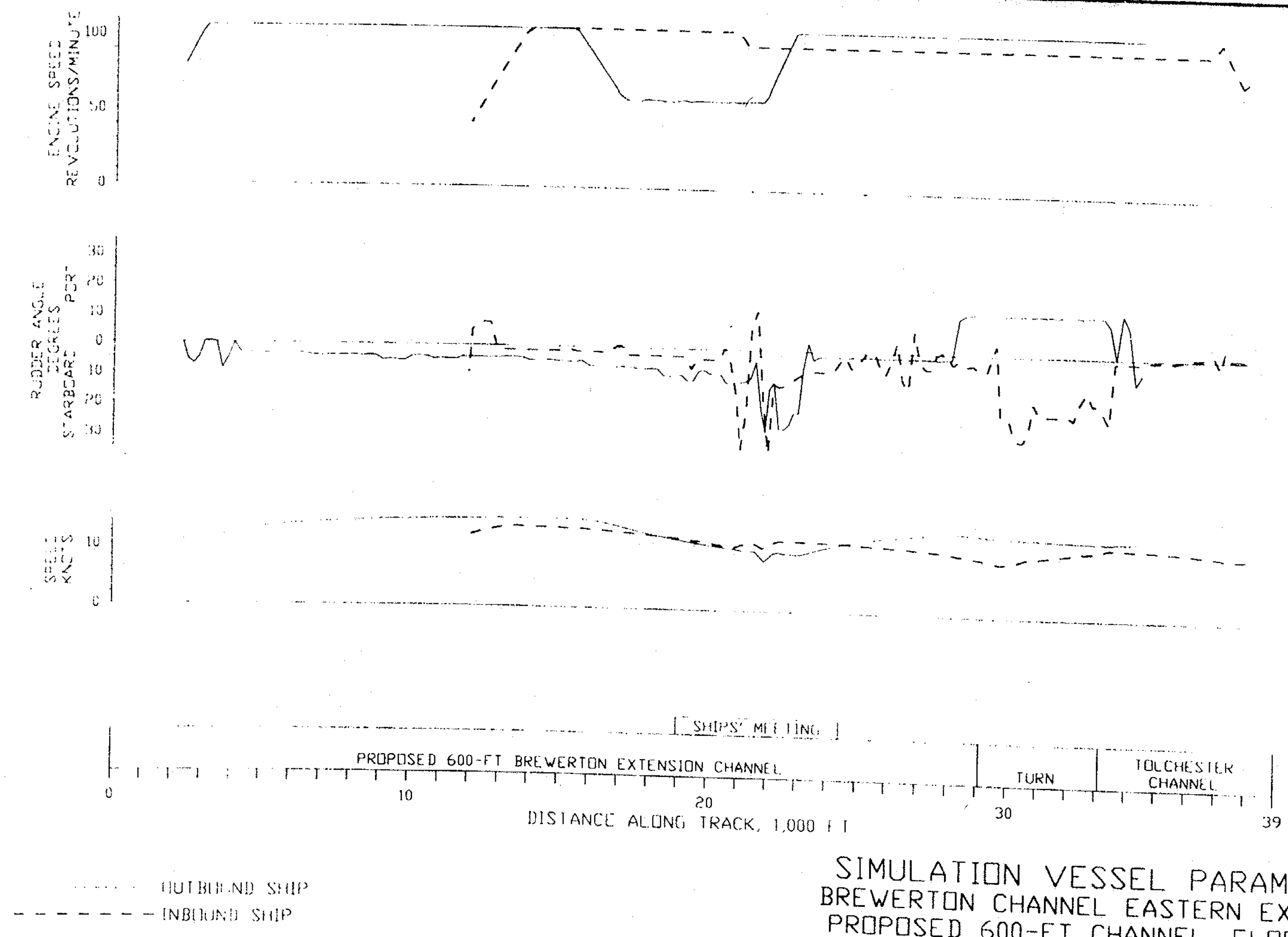
Plate 60

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

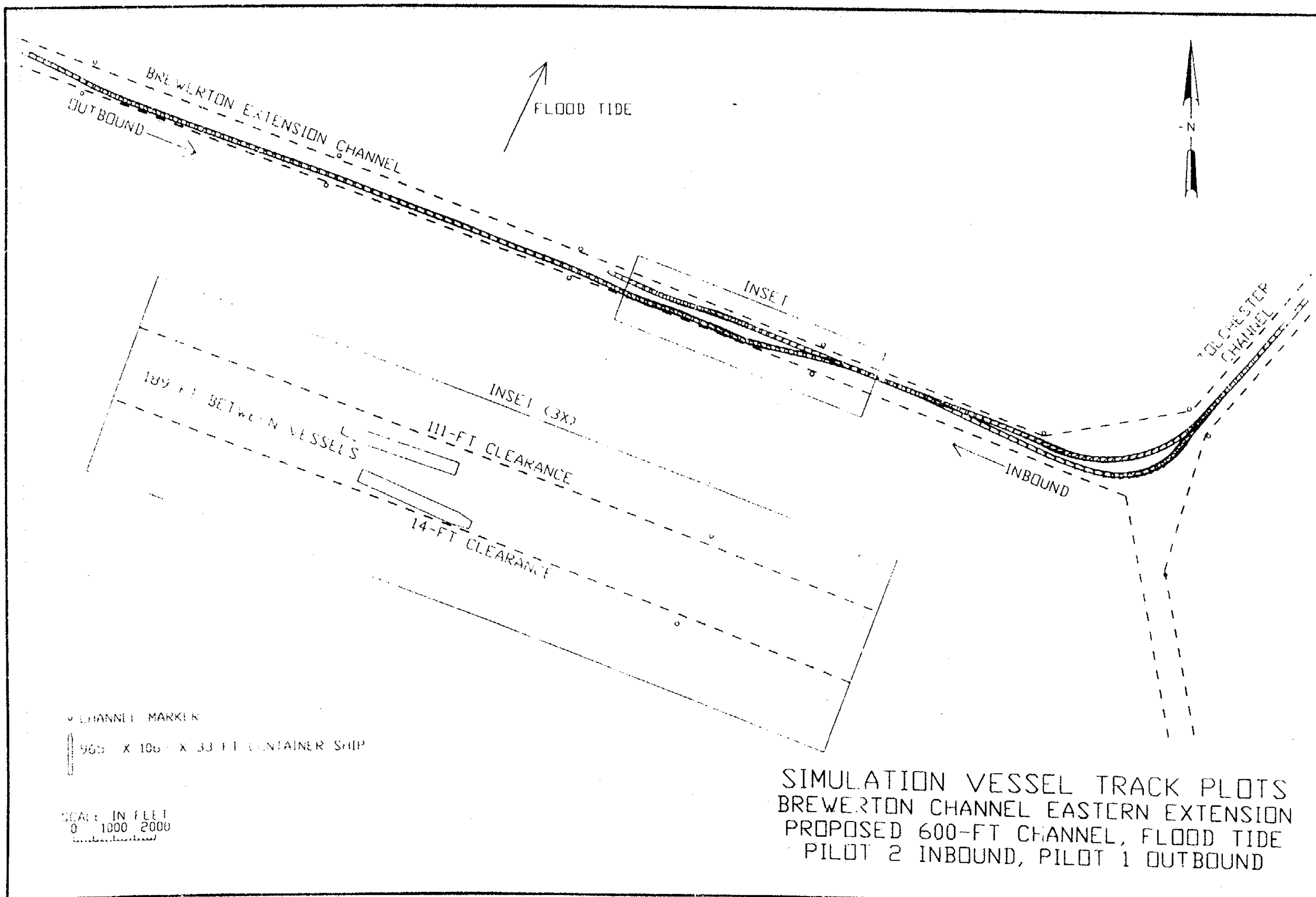
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

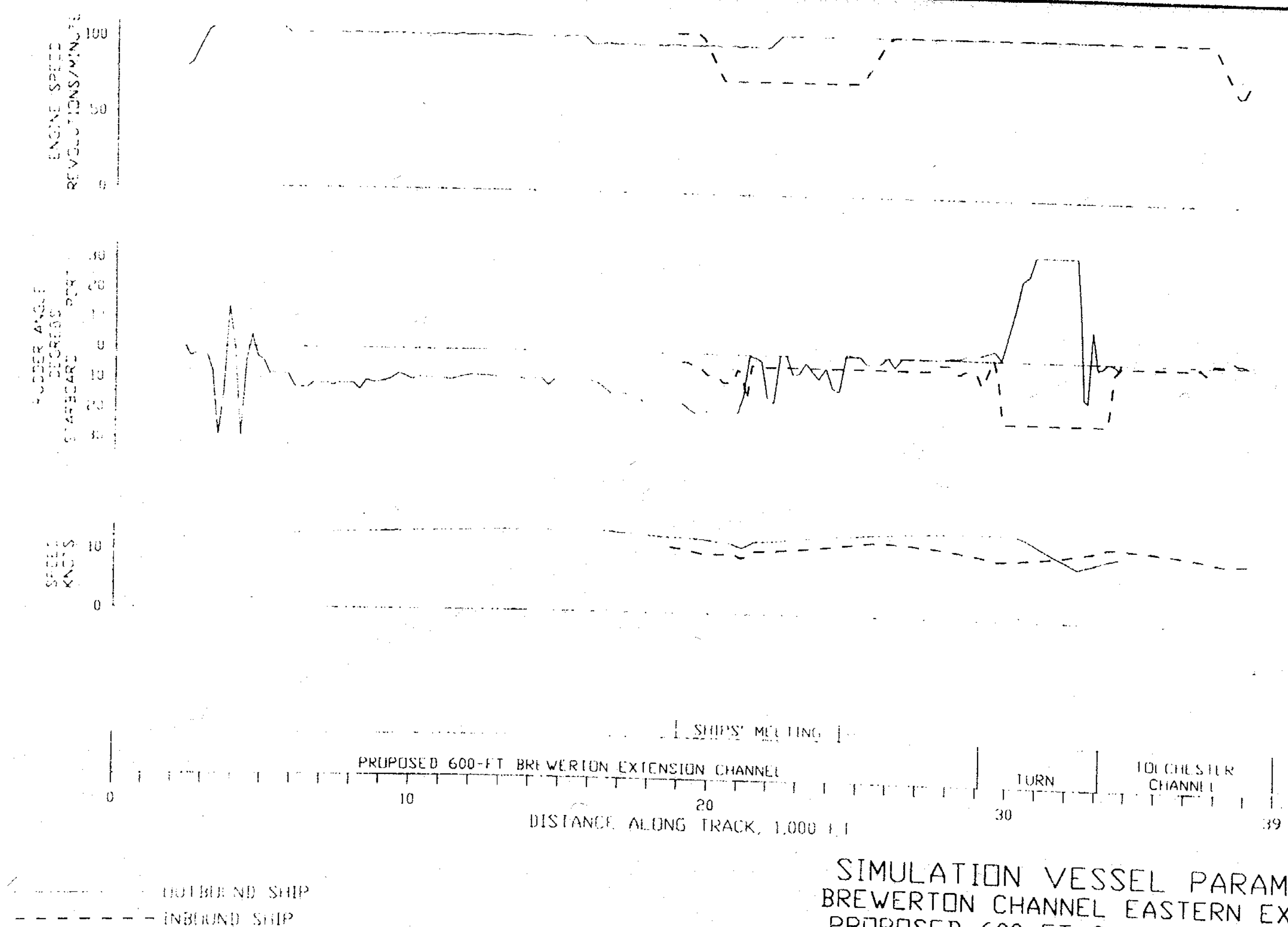
Plate 62

PRELIMINARY



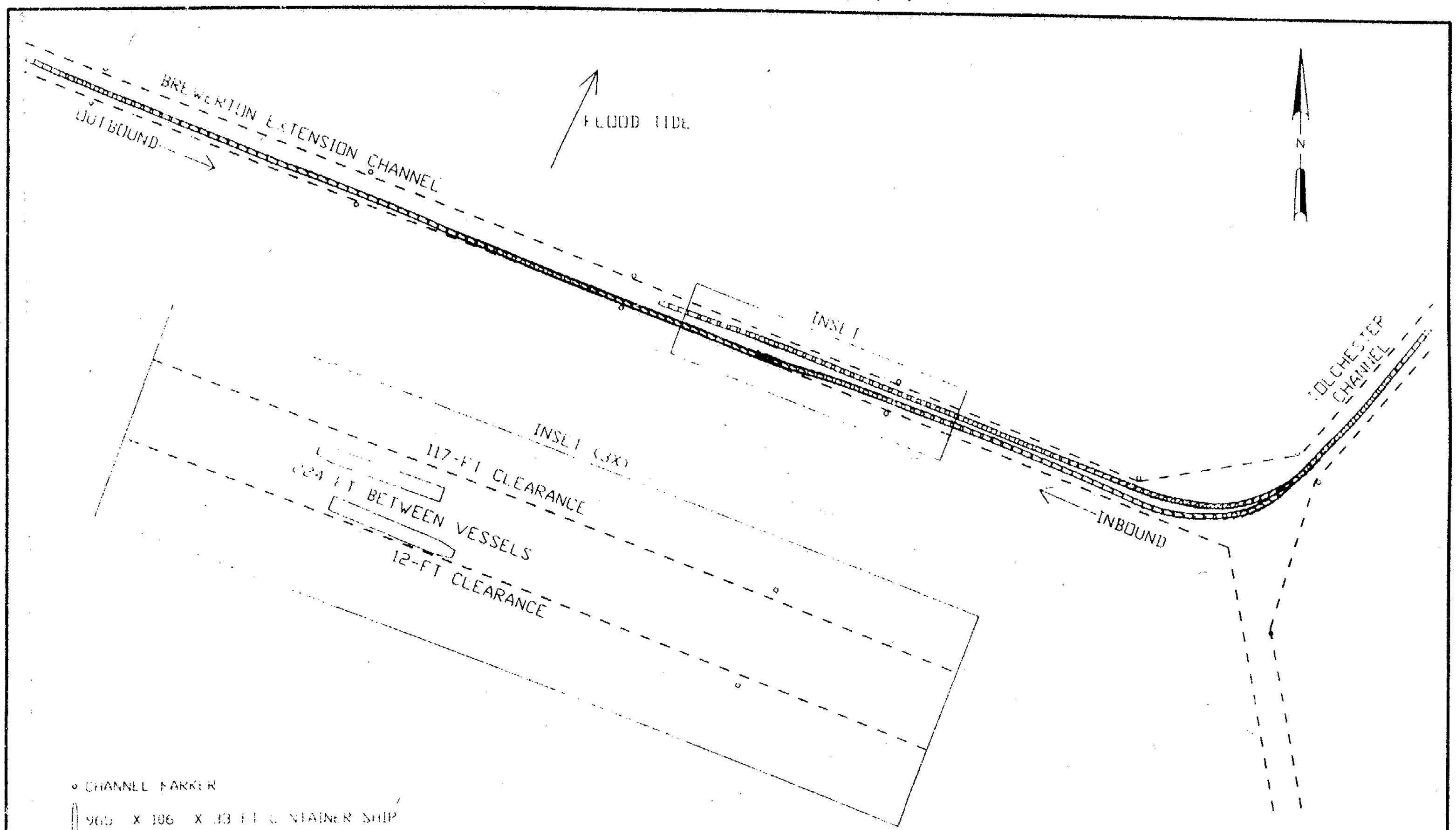
SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 65

PRELIMINARY

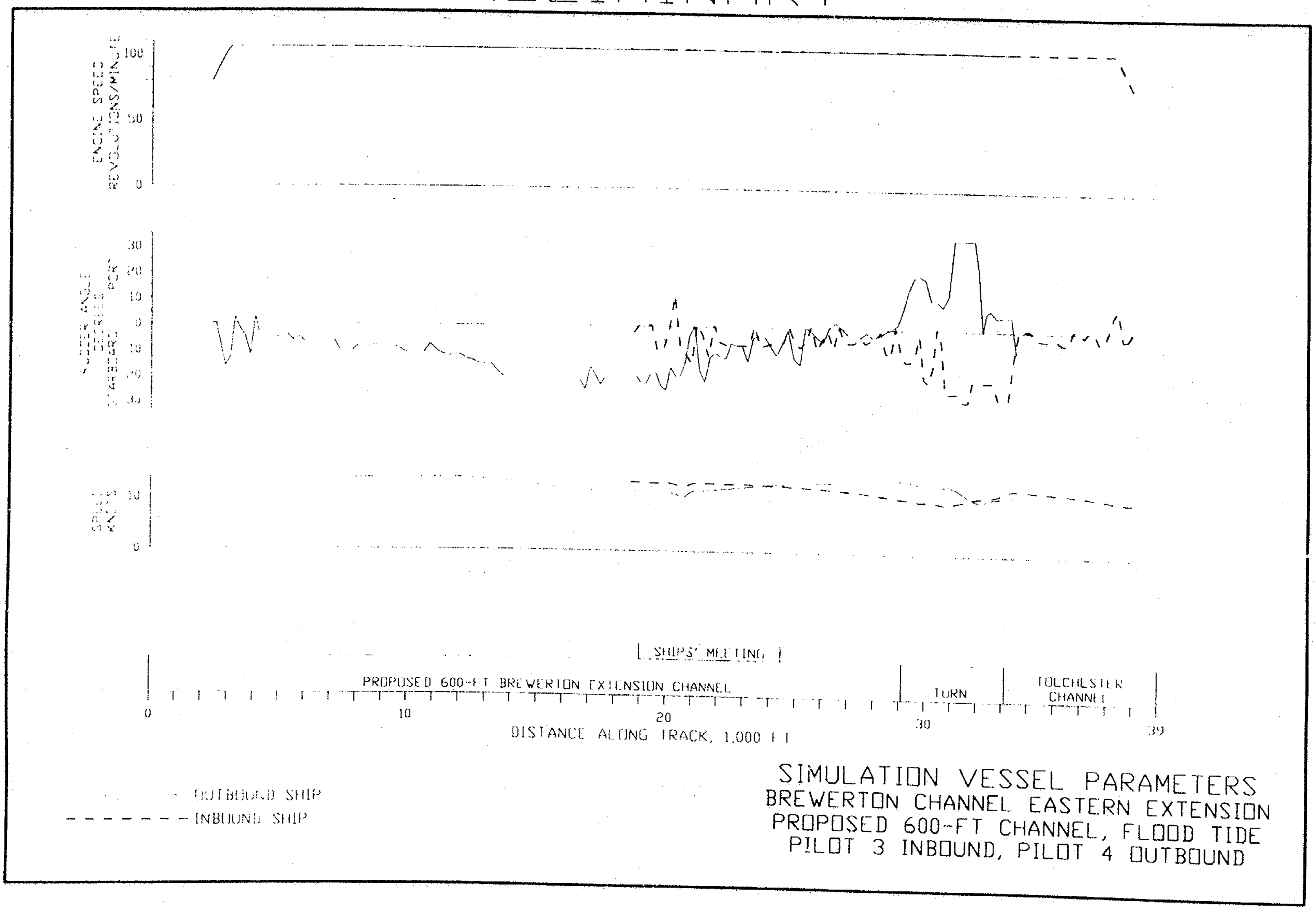
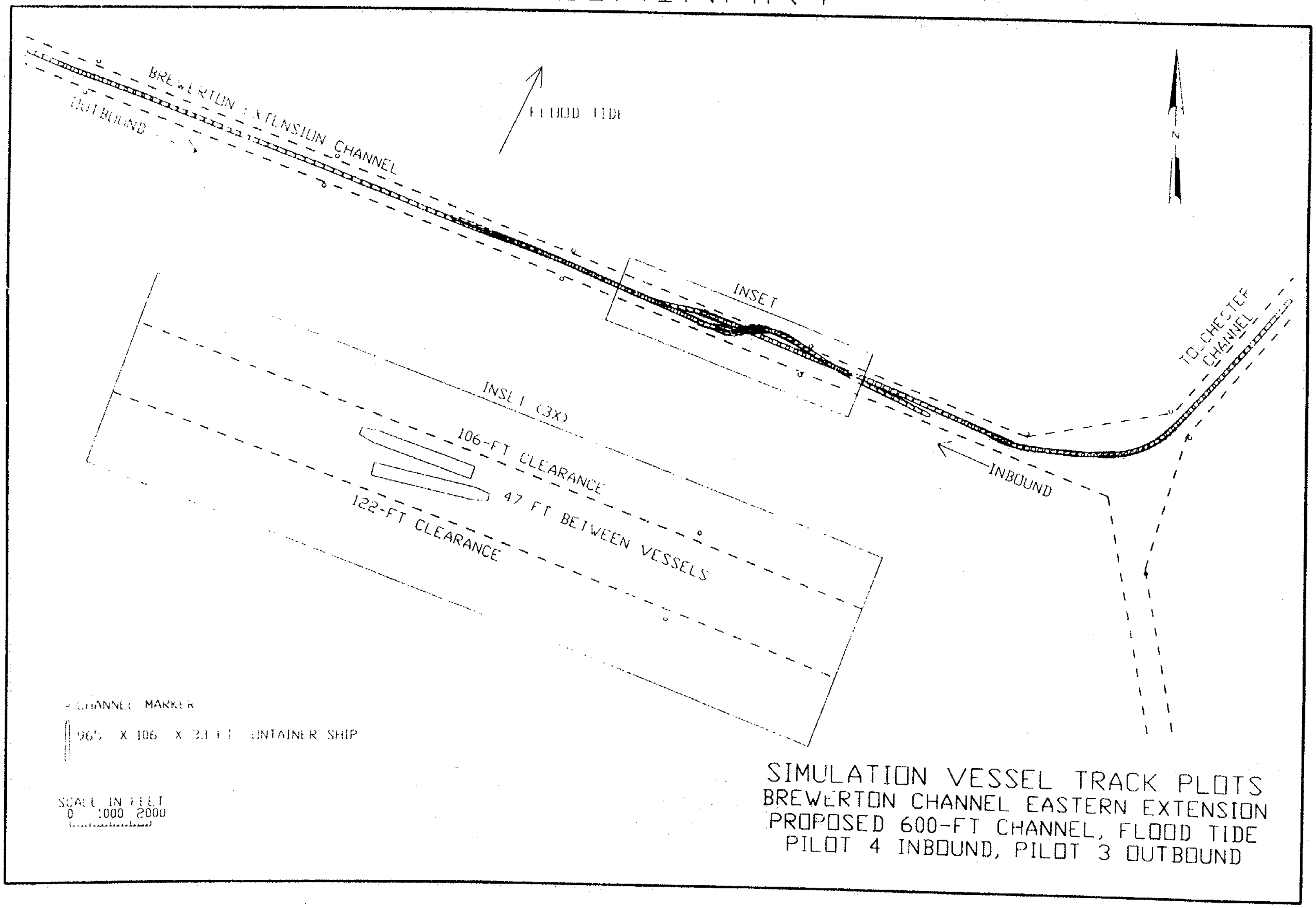
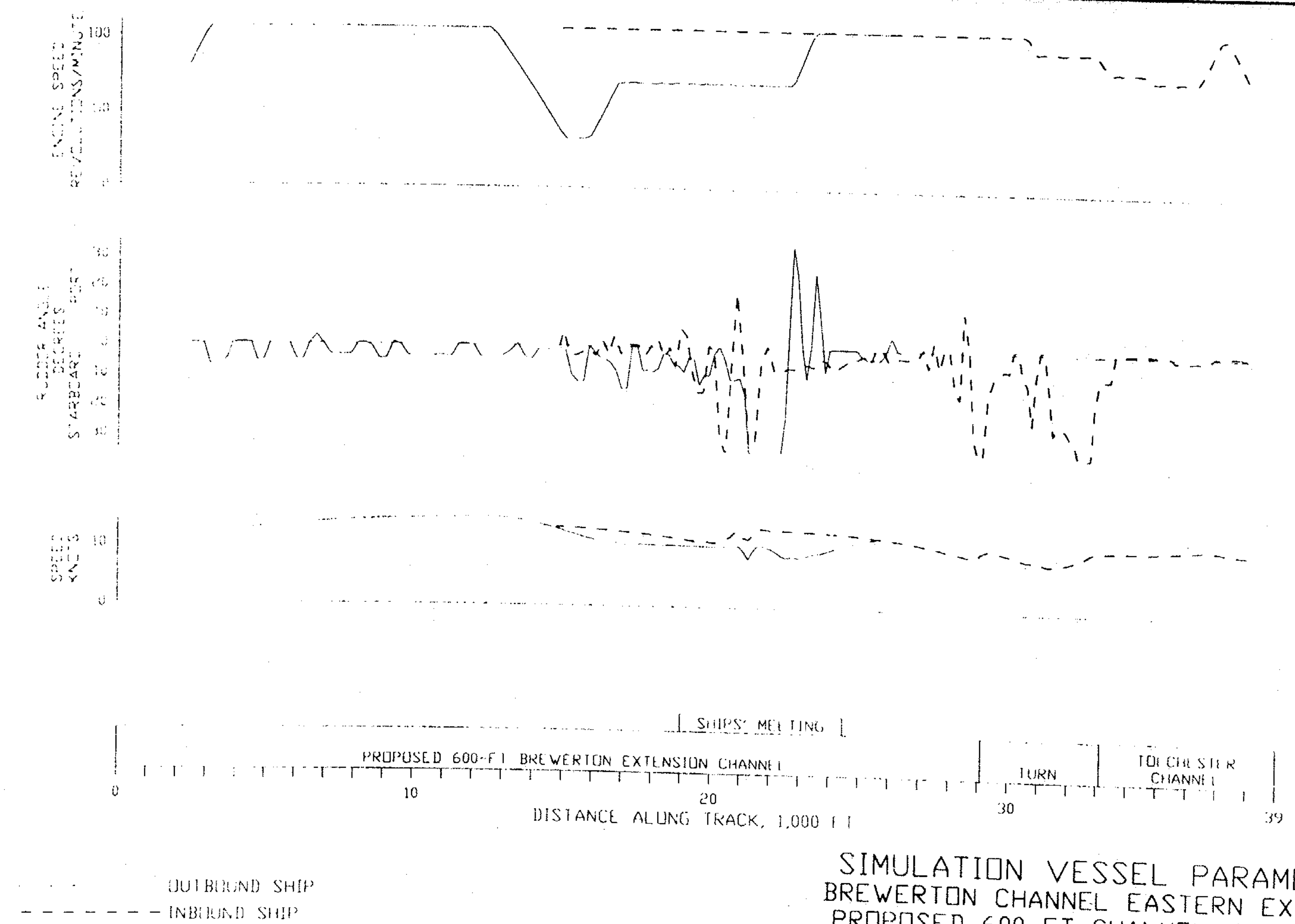


Plate 66

PRELIMINARY



PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 68

PRELIMINARY

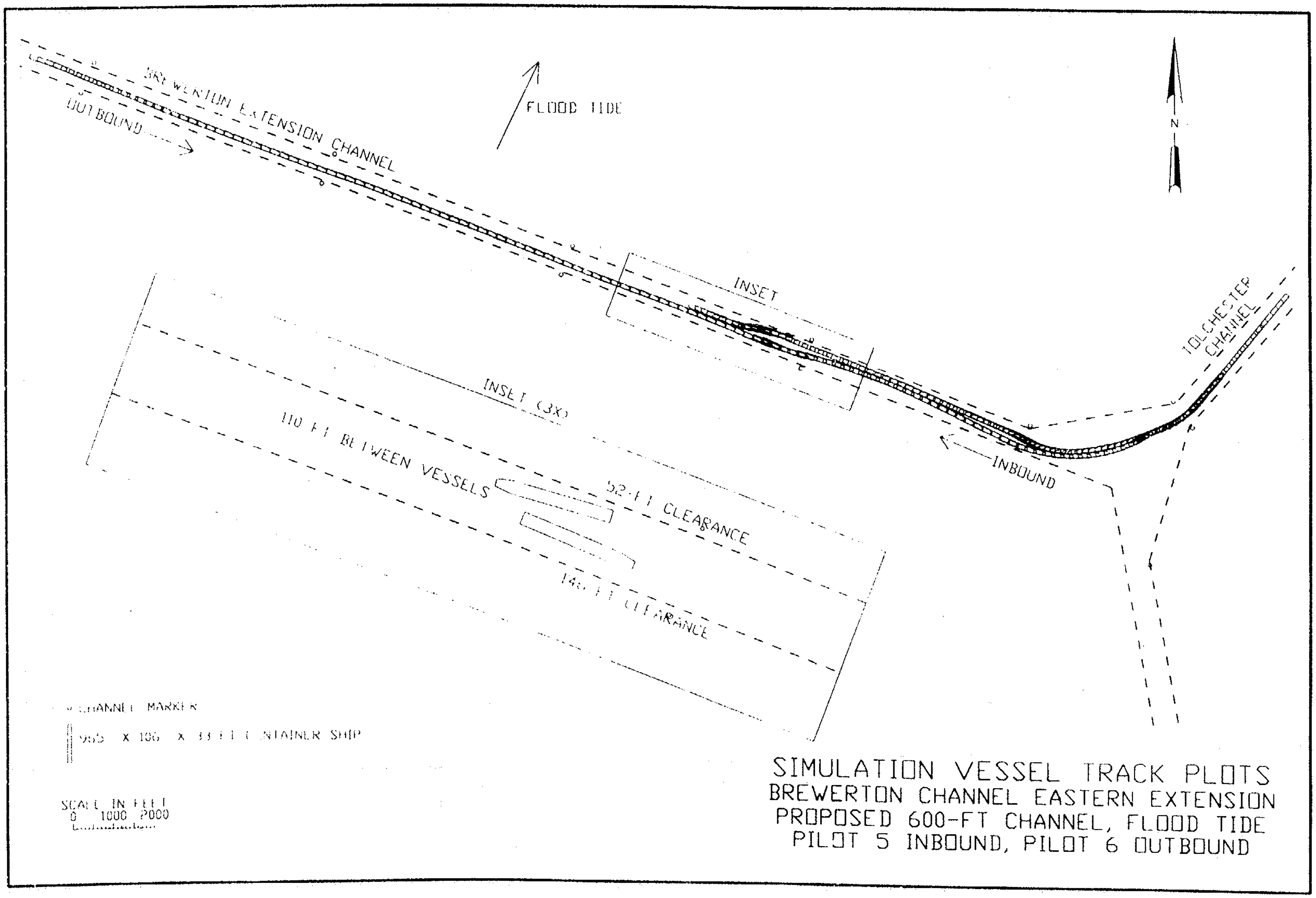
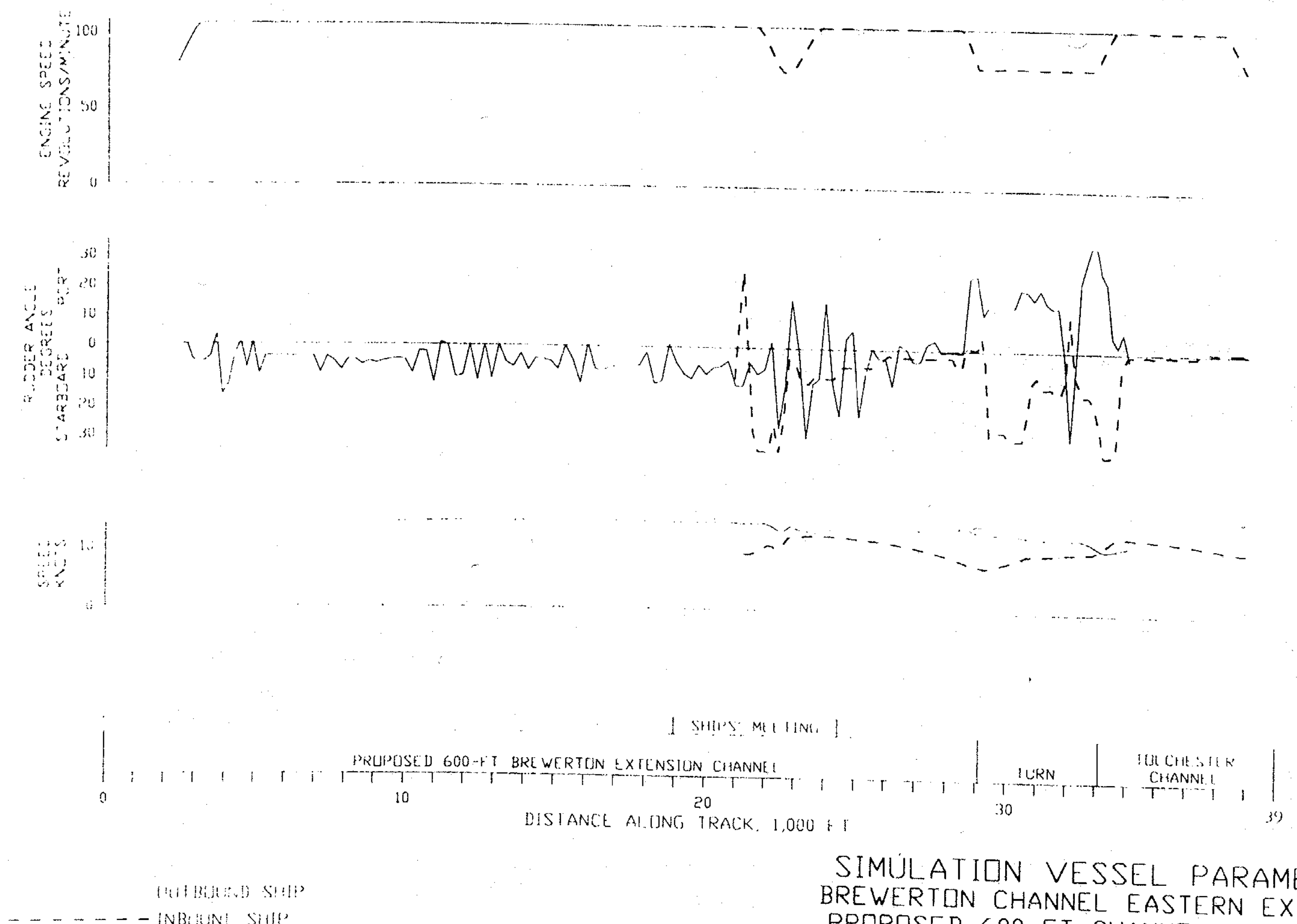


Plate 69

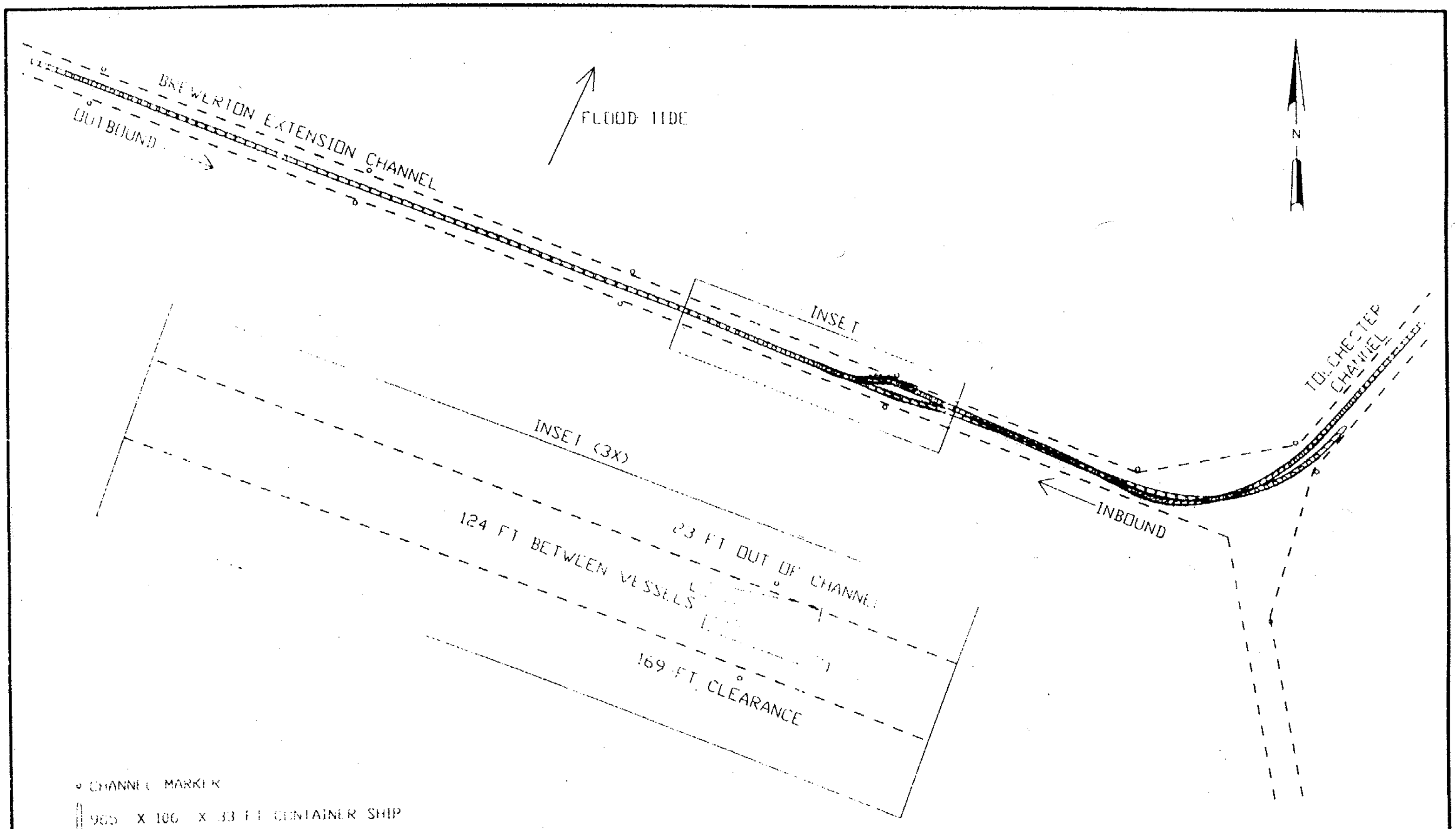
PRELIMINARY



SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

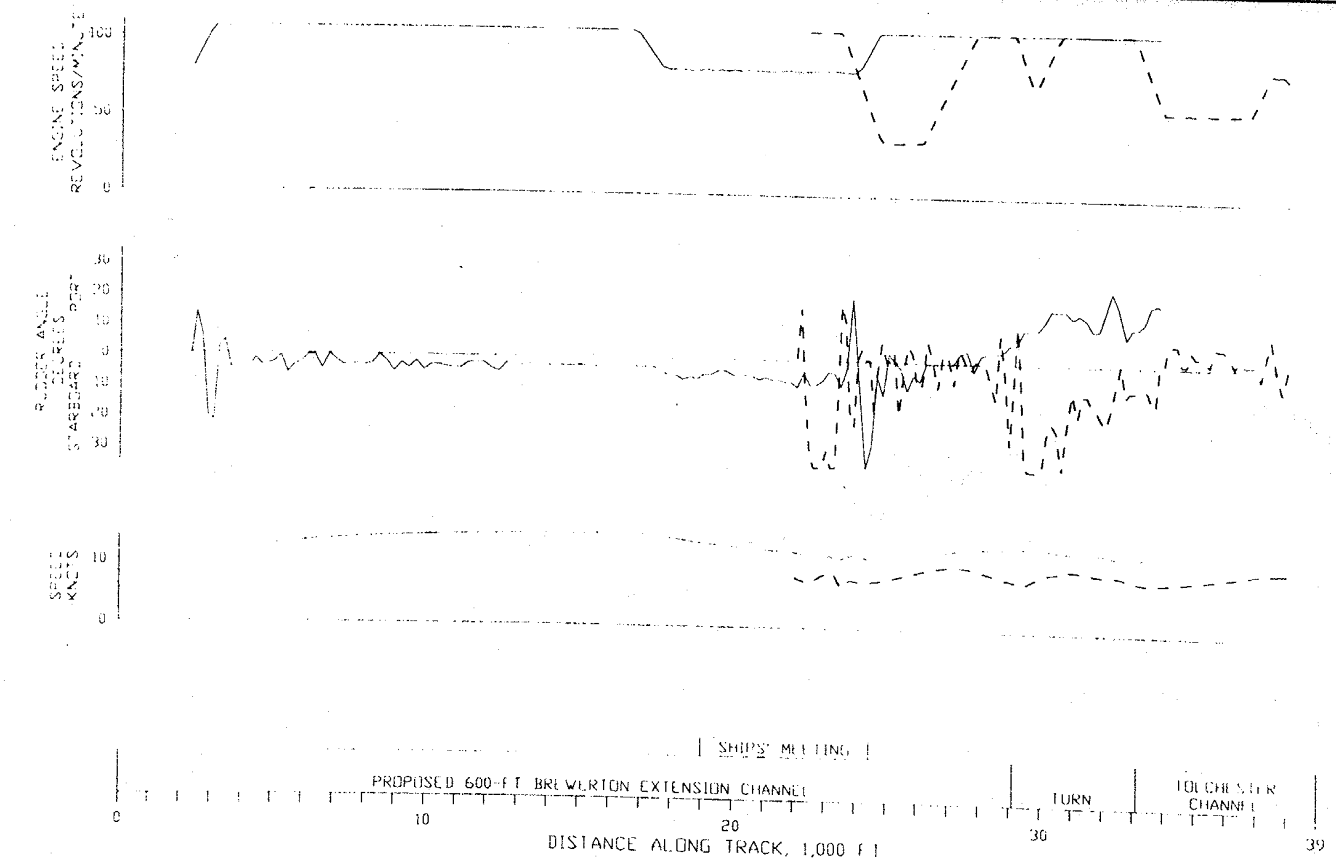
Plate 70

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

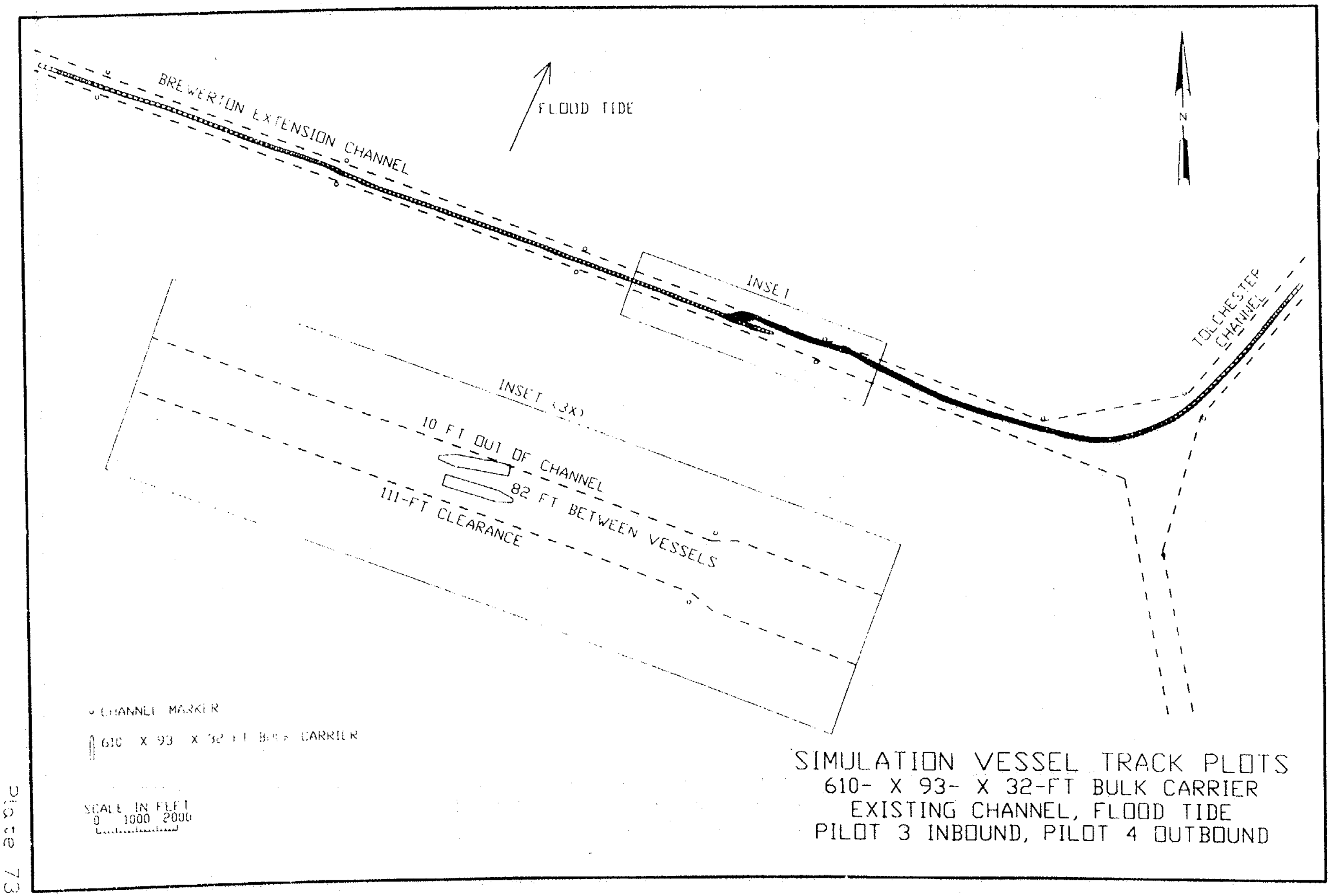
PRELIMINARY



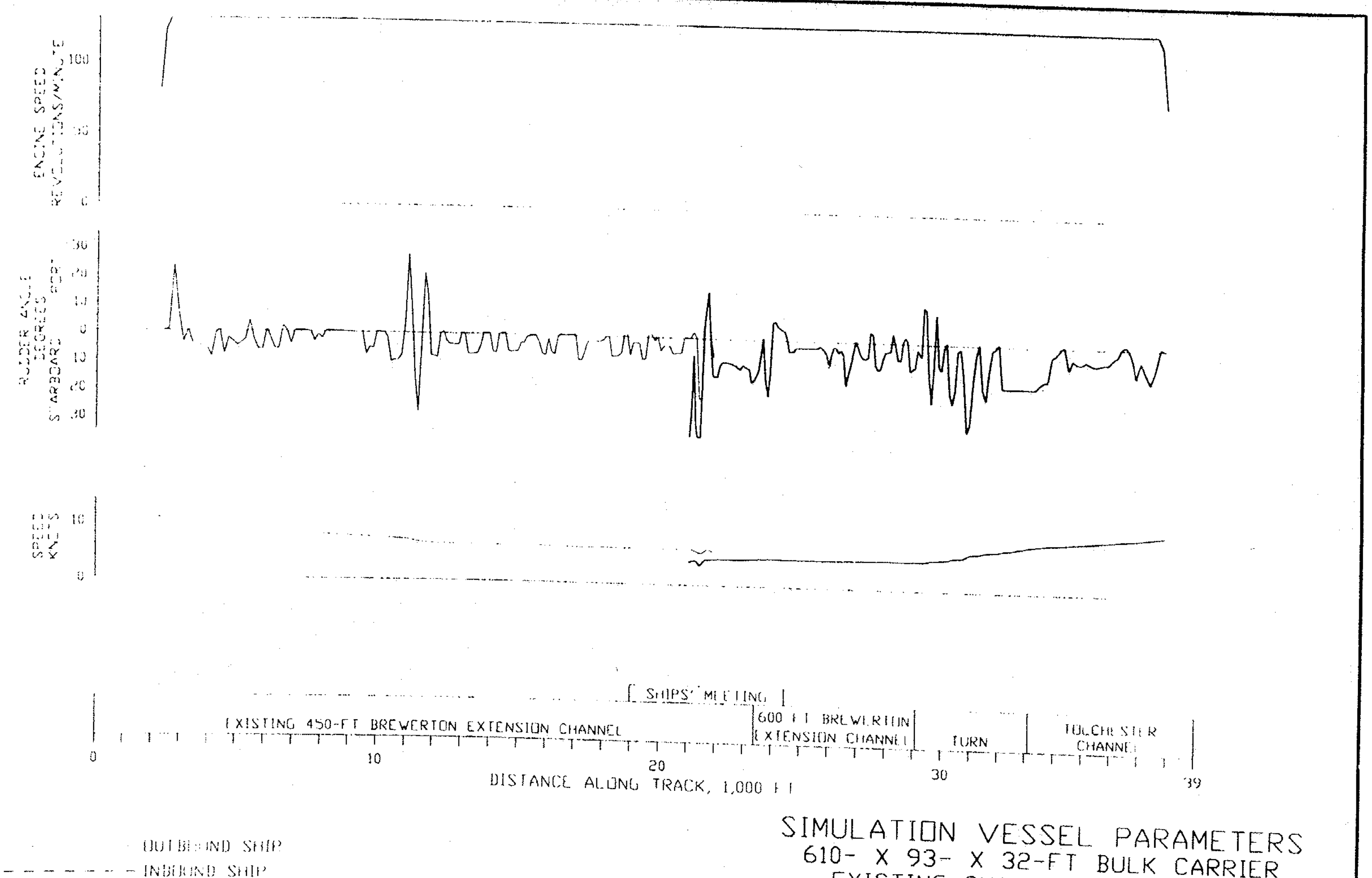
SIMULATION VESSEL PARAMETERS
BREWERTON CHANNEL EASTERN EXTENSION
PROPOSED 600-FT CHANNEL, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 72

PRELIMINARY



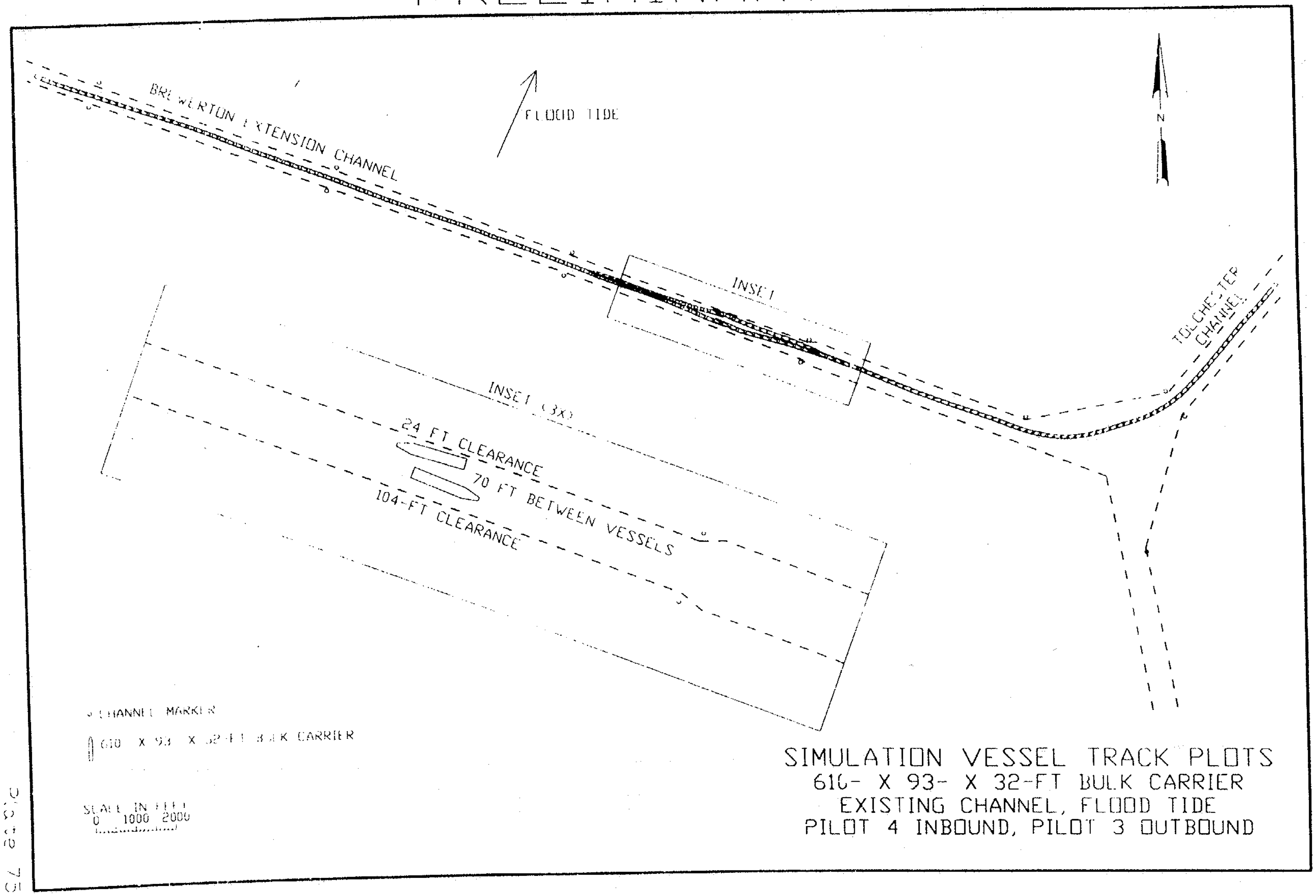
PRELIMINARY



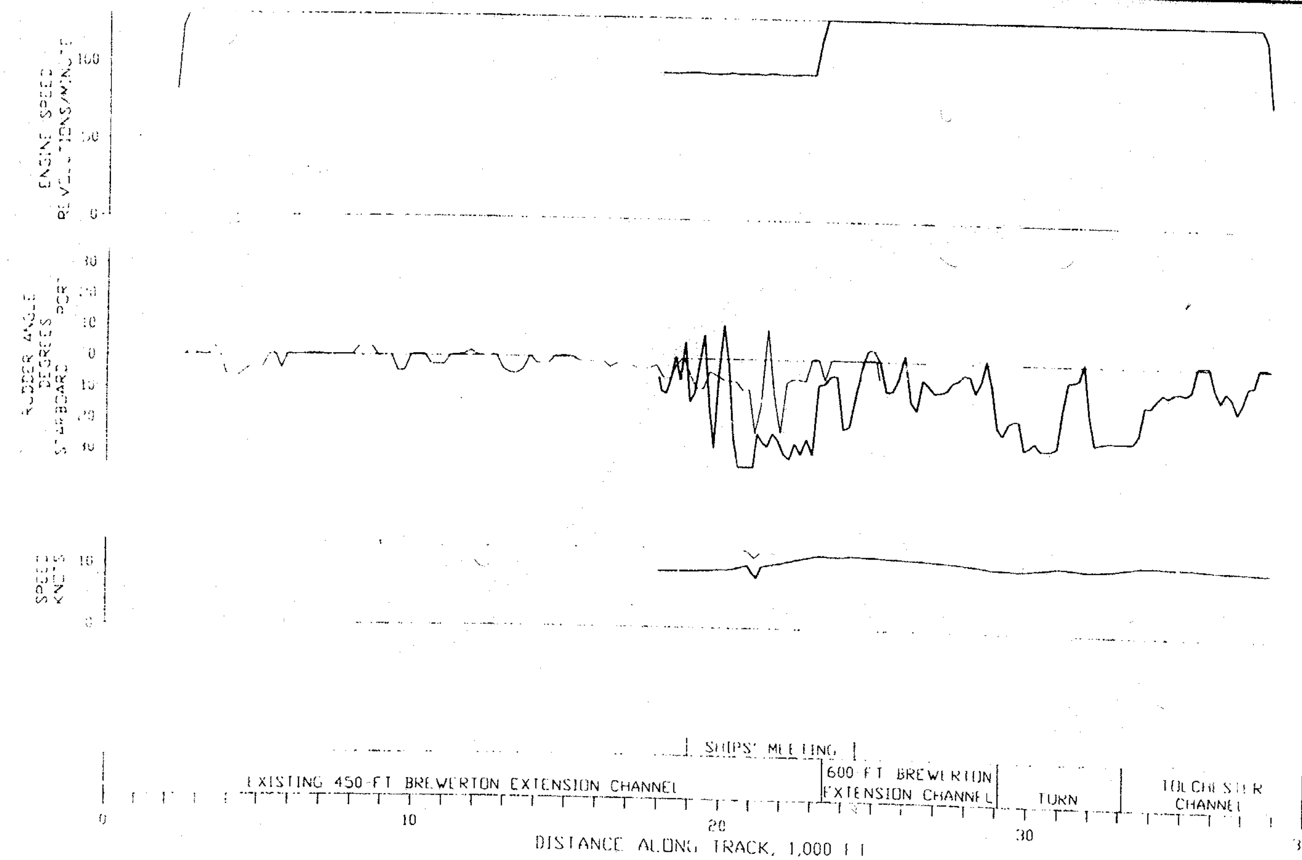
SIMULATION VESSEL PARAMETERS
610- X 93- X 32-FT BULK CARRIER
EXISTING CHANNEL, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 74

PRELIMINARY



PRELIMINARY

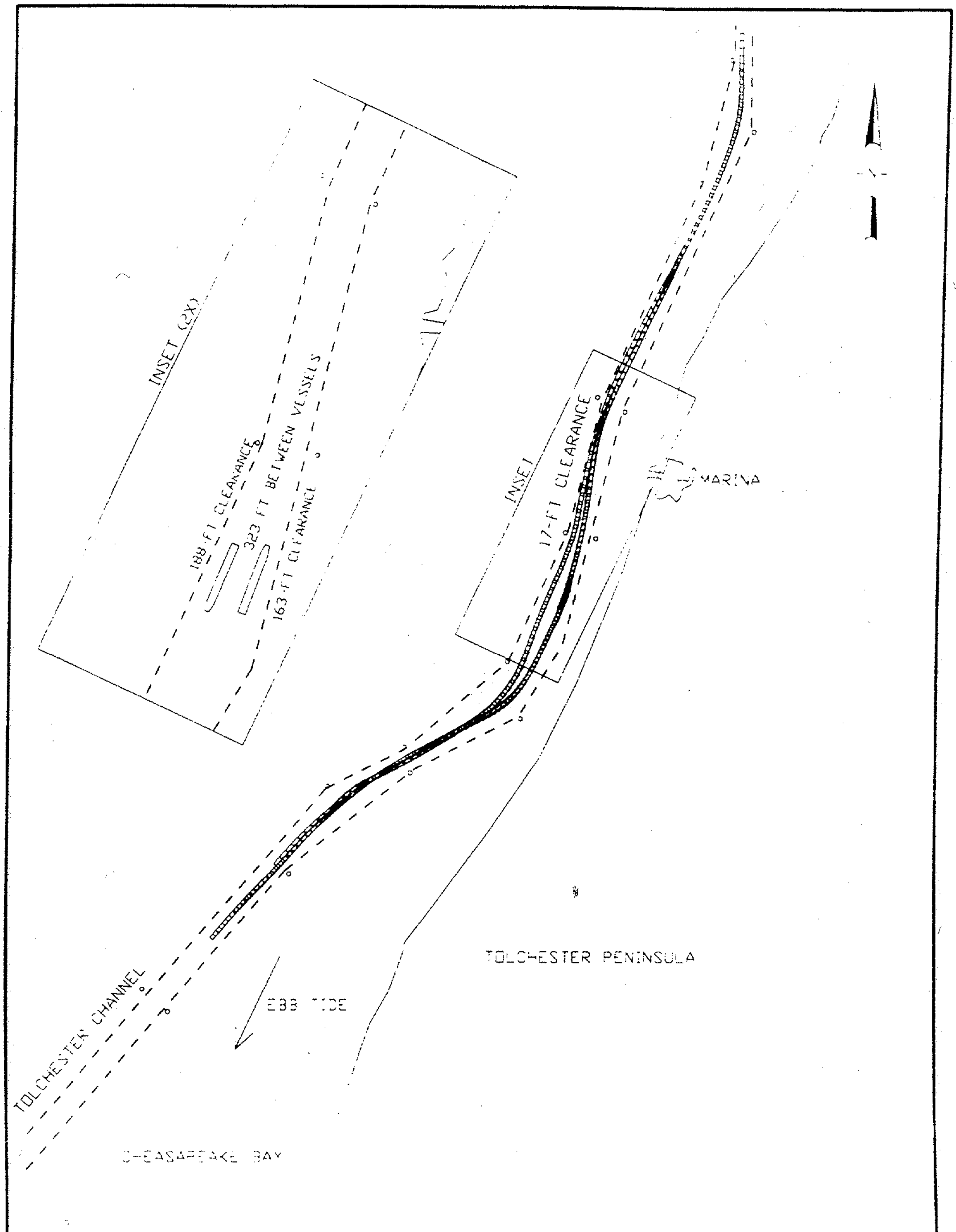


OUTBOUND SHIP
- - - - - - INBOUND SHIP

SIMULATION VESSEL PARAMETERS
610- X 93- X 32-FT BULK CARRIER
EXISTING CHANNEL, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 76

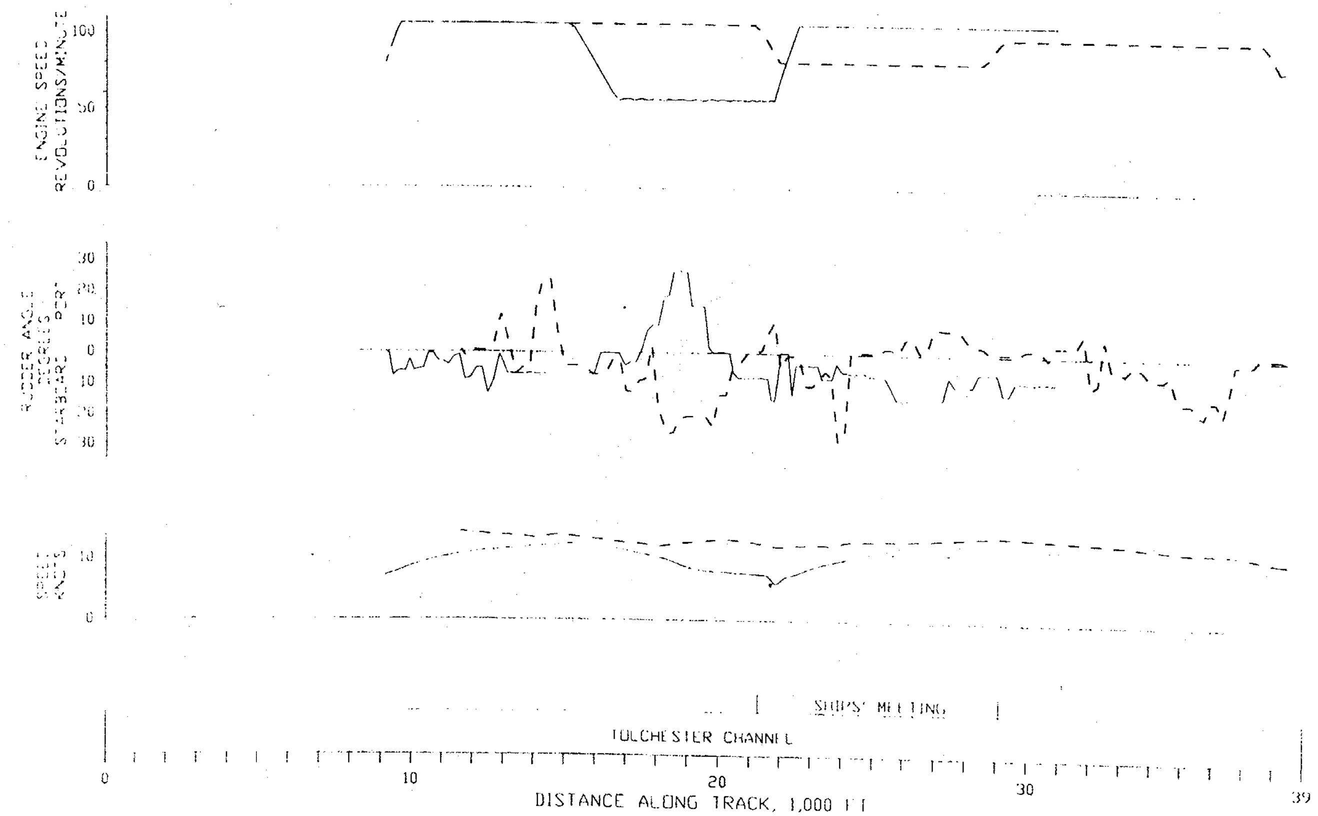
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 77

PRELIMINARY

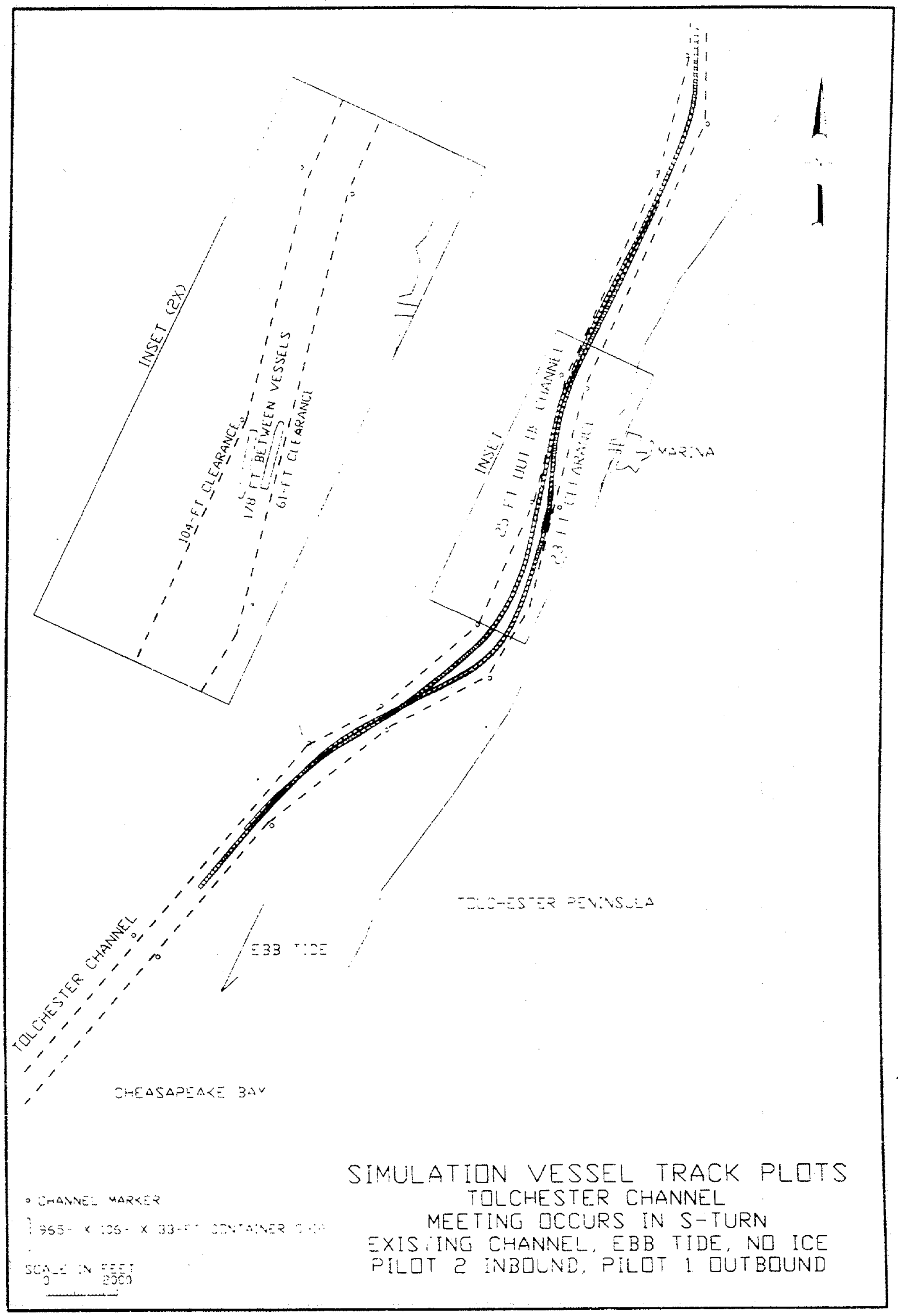


OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 78

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

PRELIMINARY

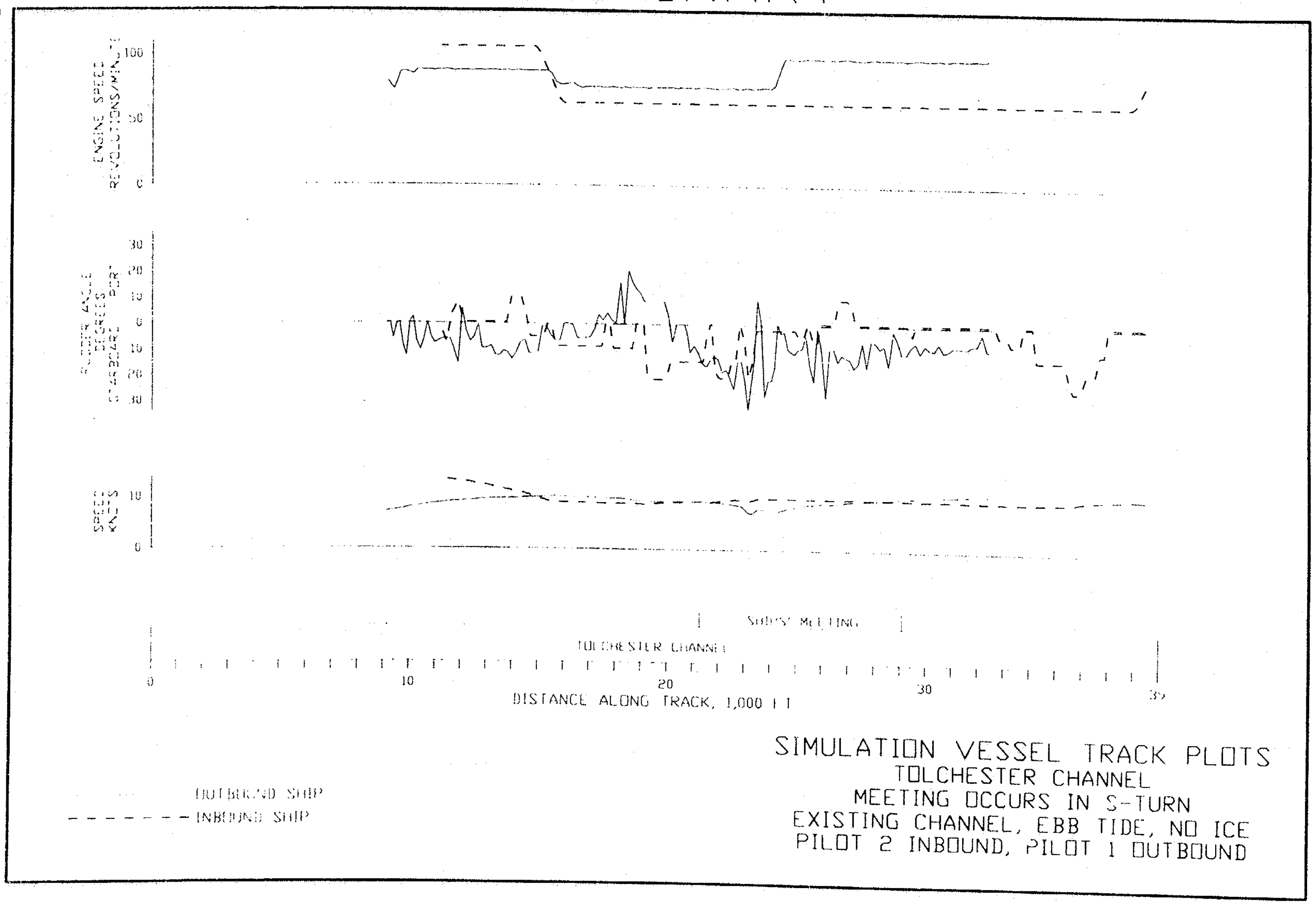
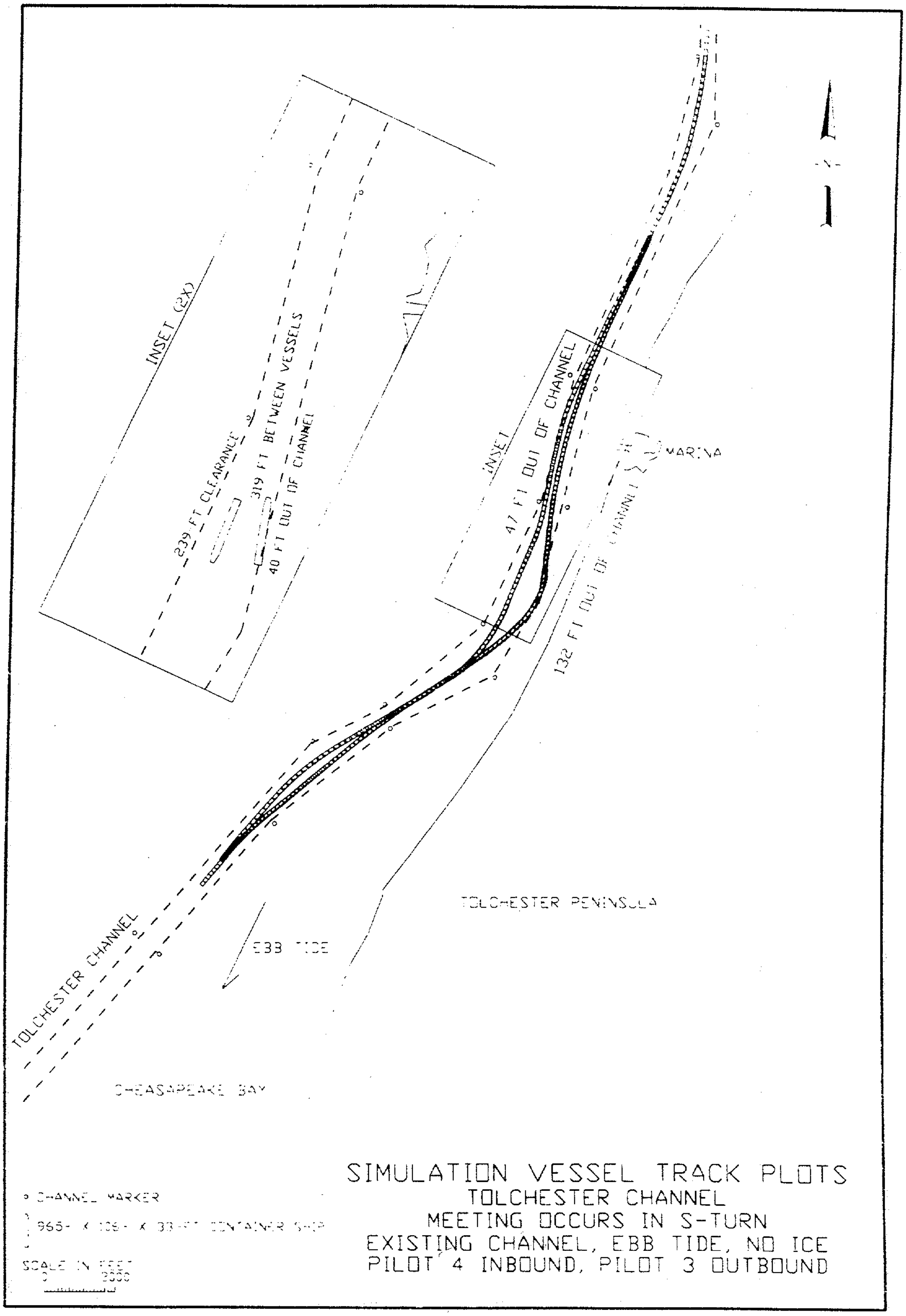
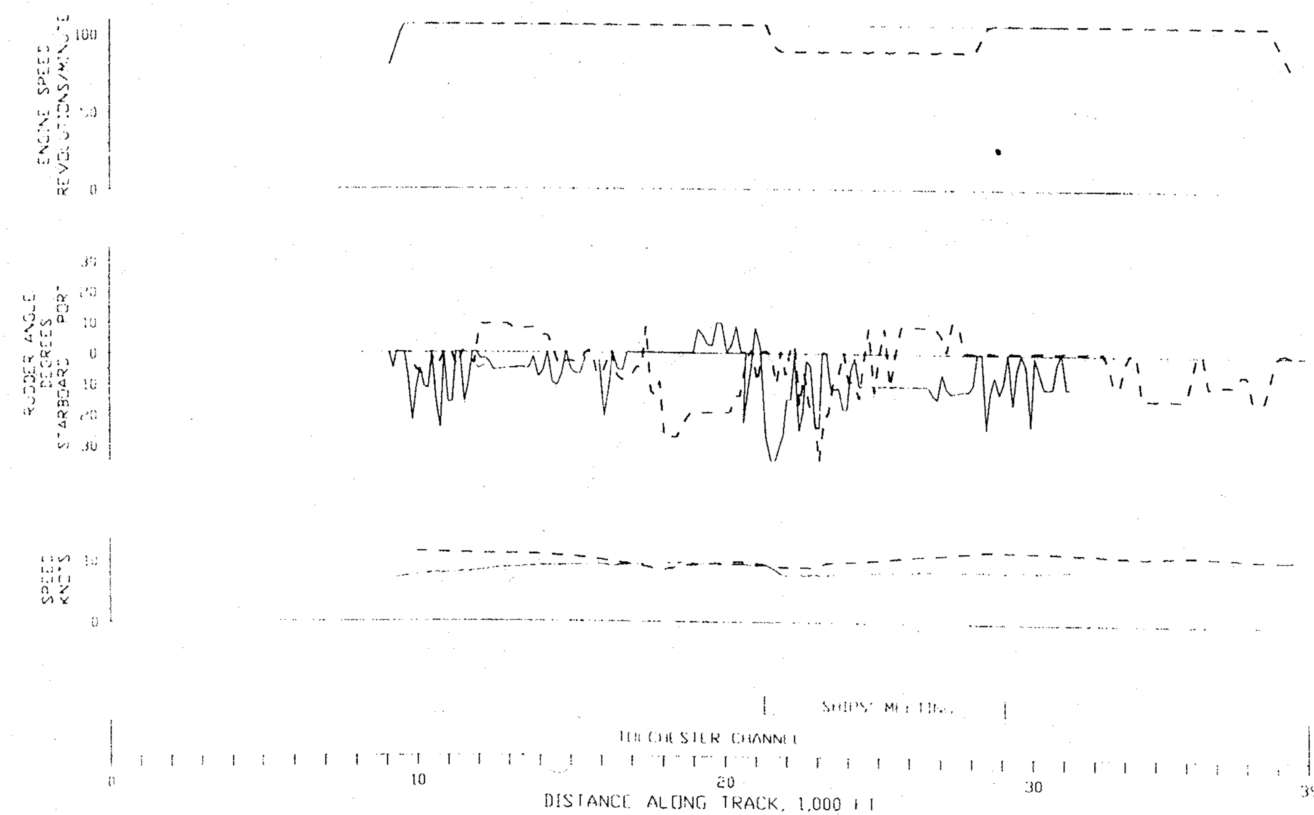


Plate 80

PRELIMINARY



PRELIMINARY

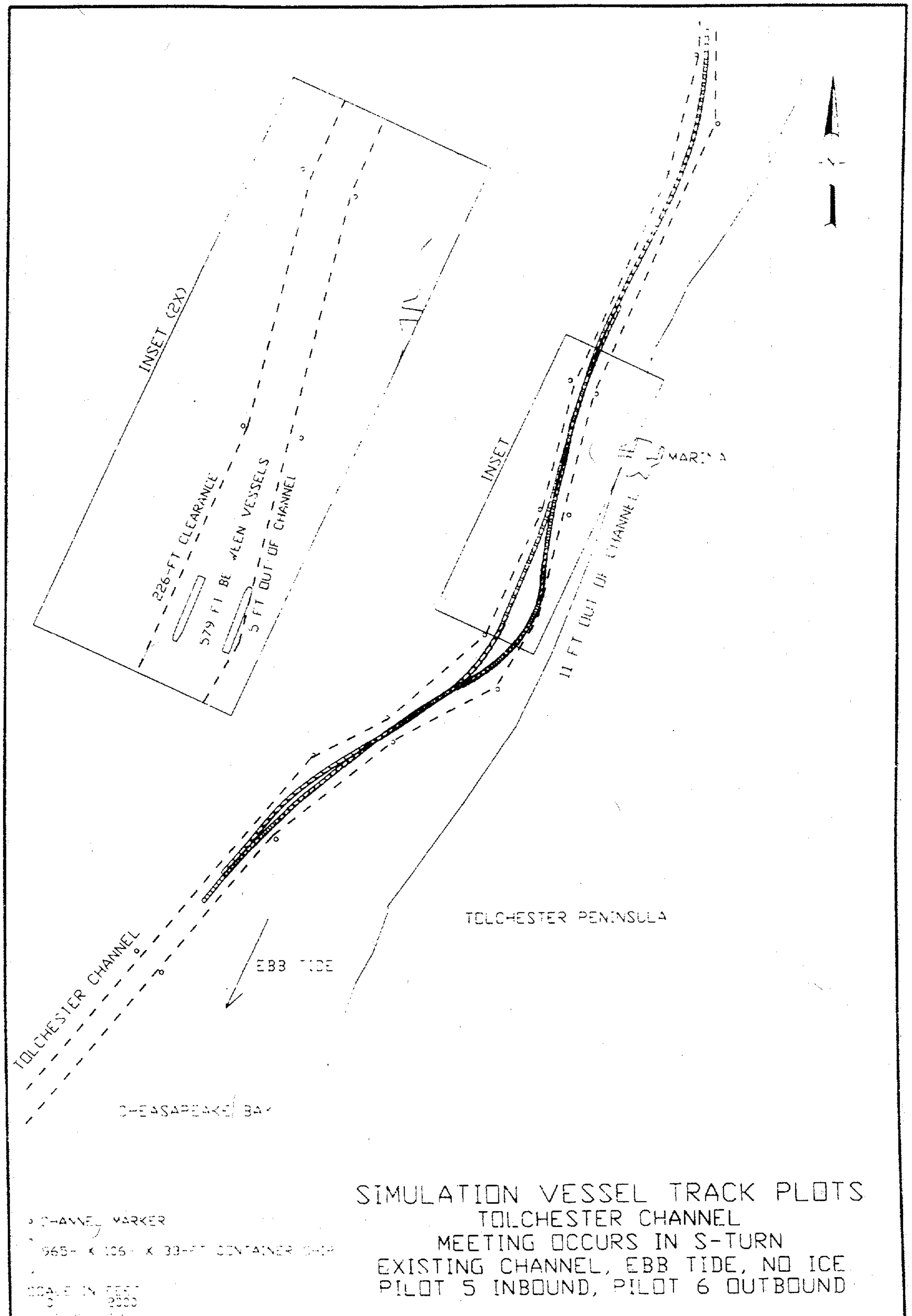


SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

OUTBOUND SHIP
- - - - - - - INBOUND SHIP

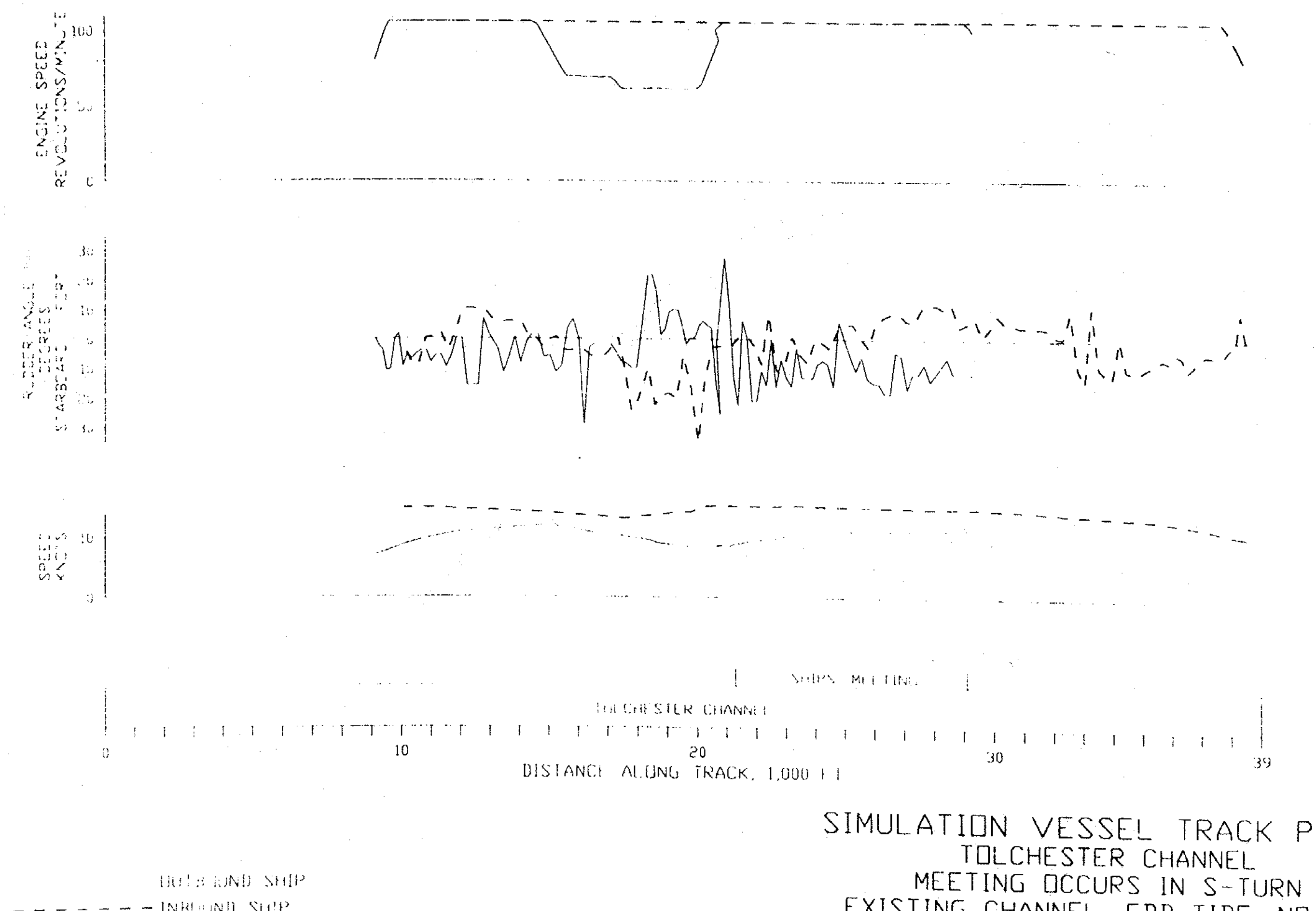
Plate 82

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

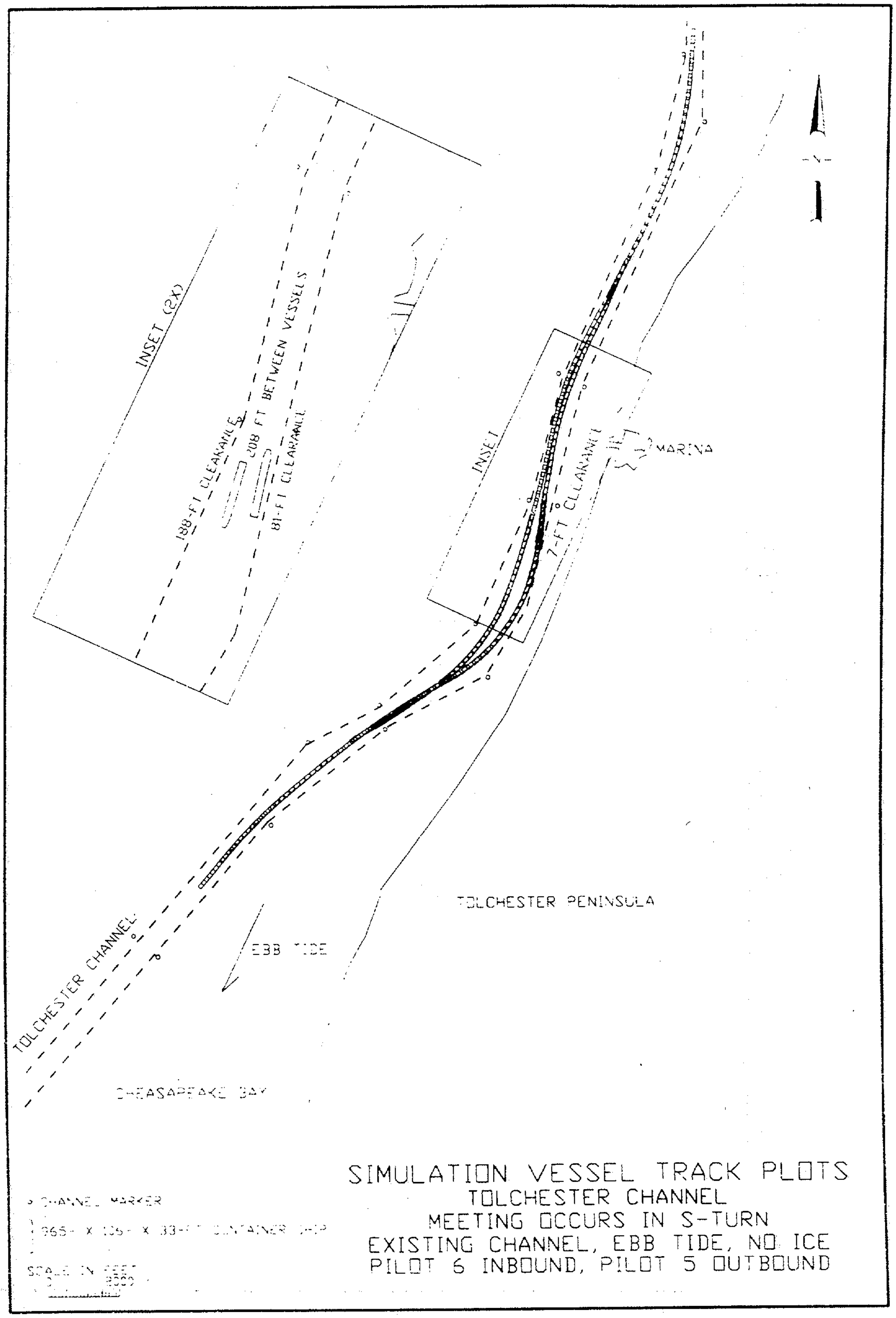
PRELIMINARY



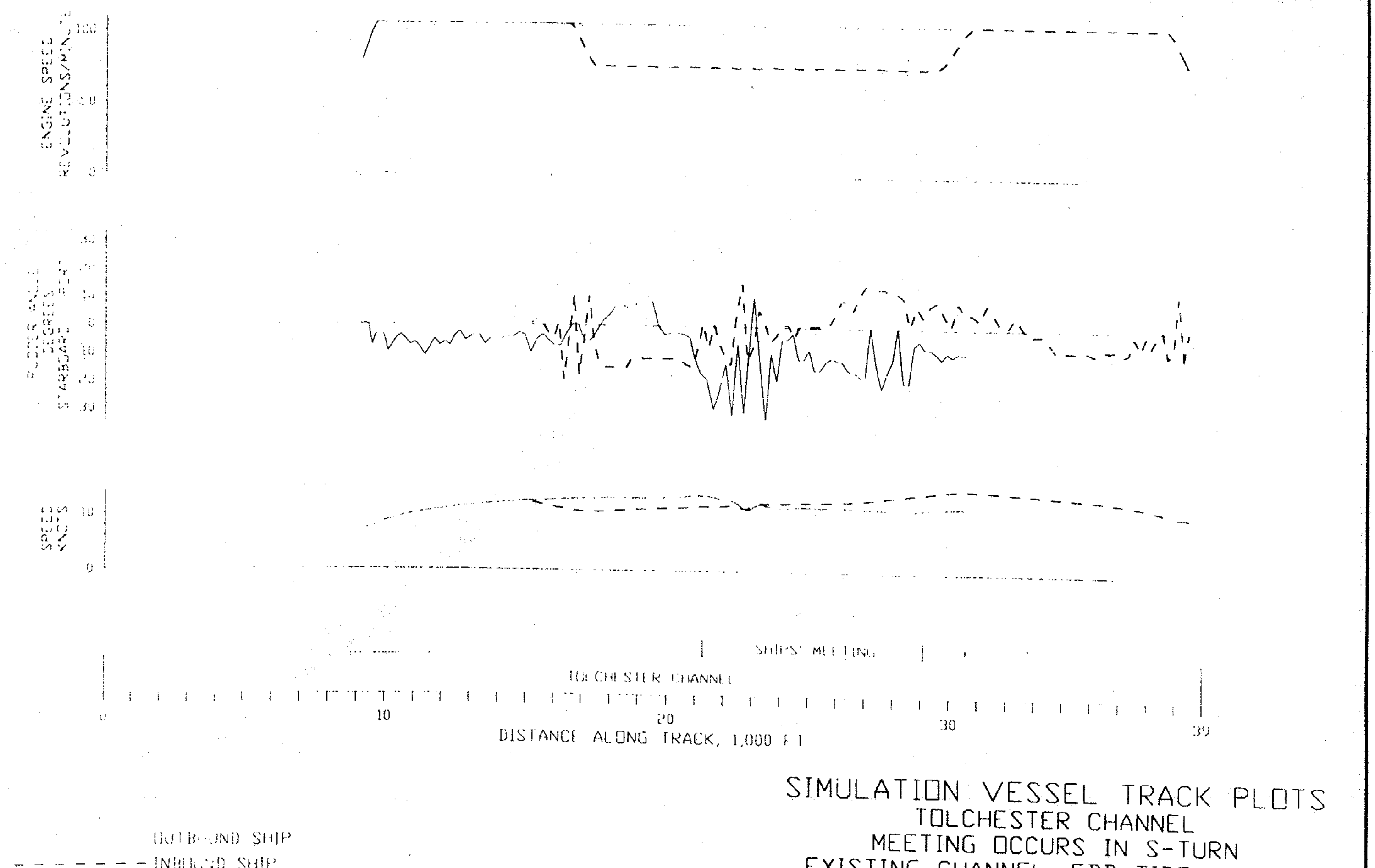
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 84

PRELIMINARY



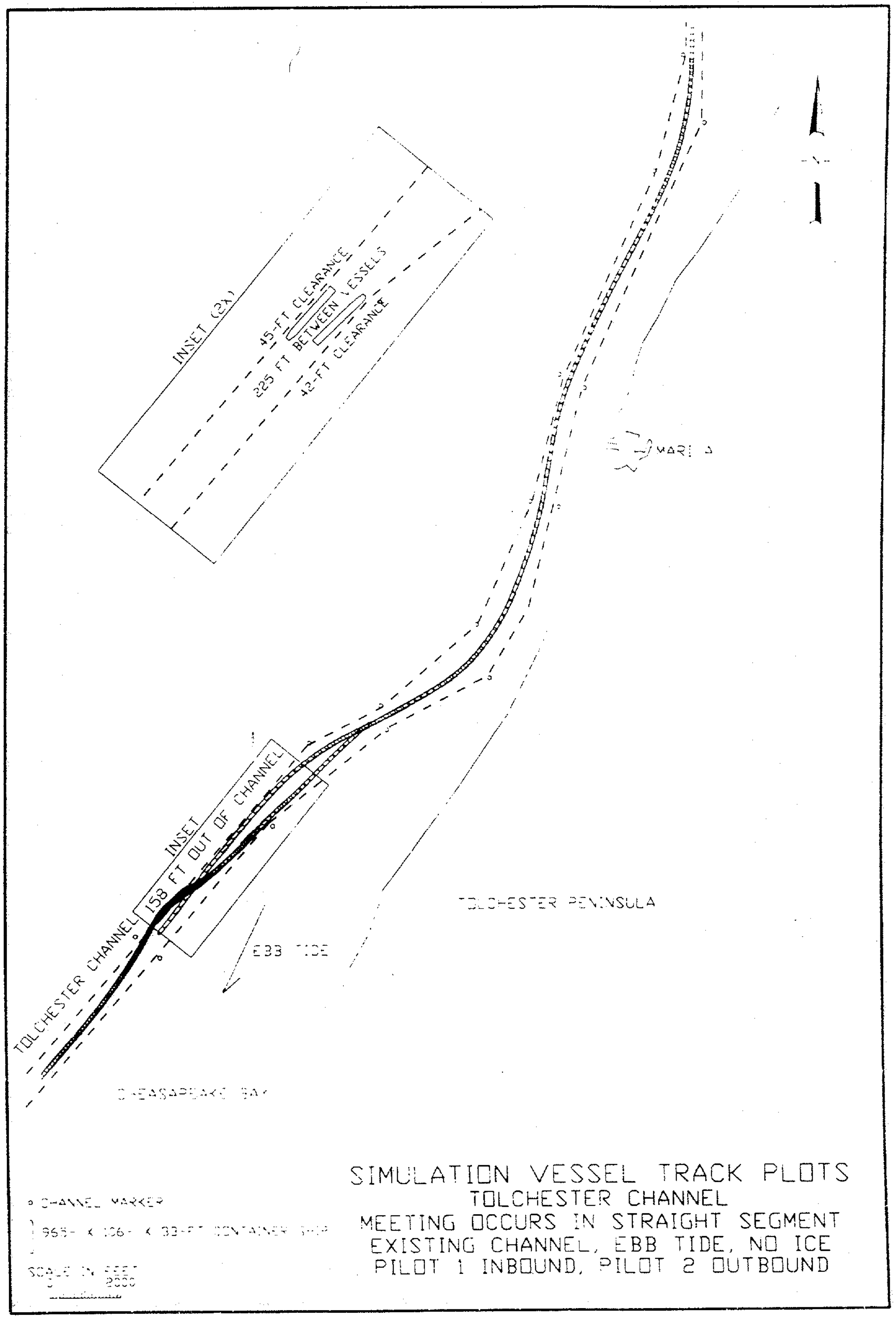
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

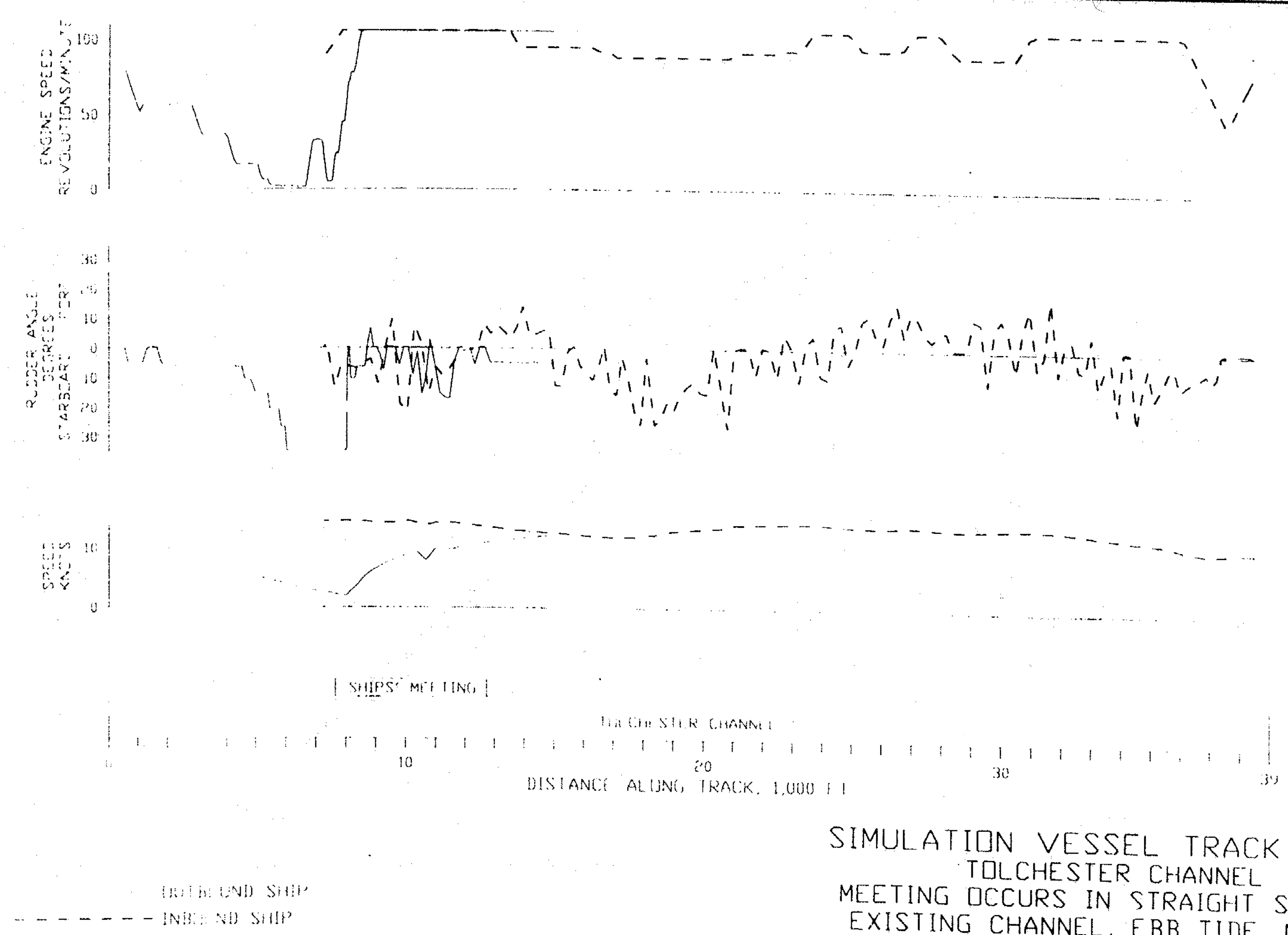
Plate 86

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

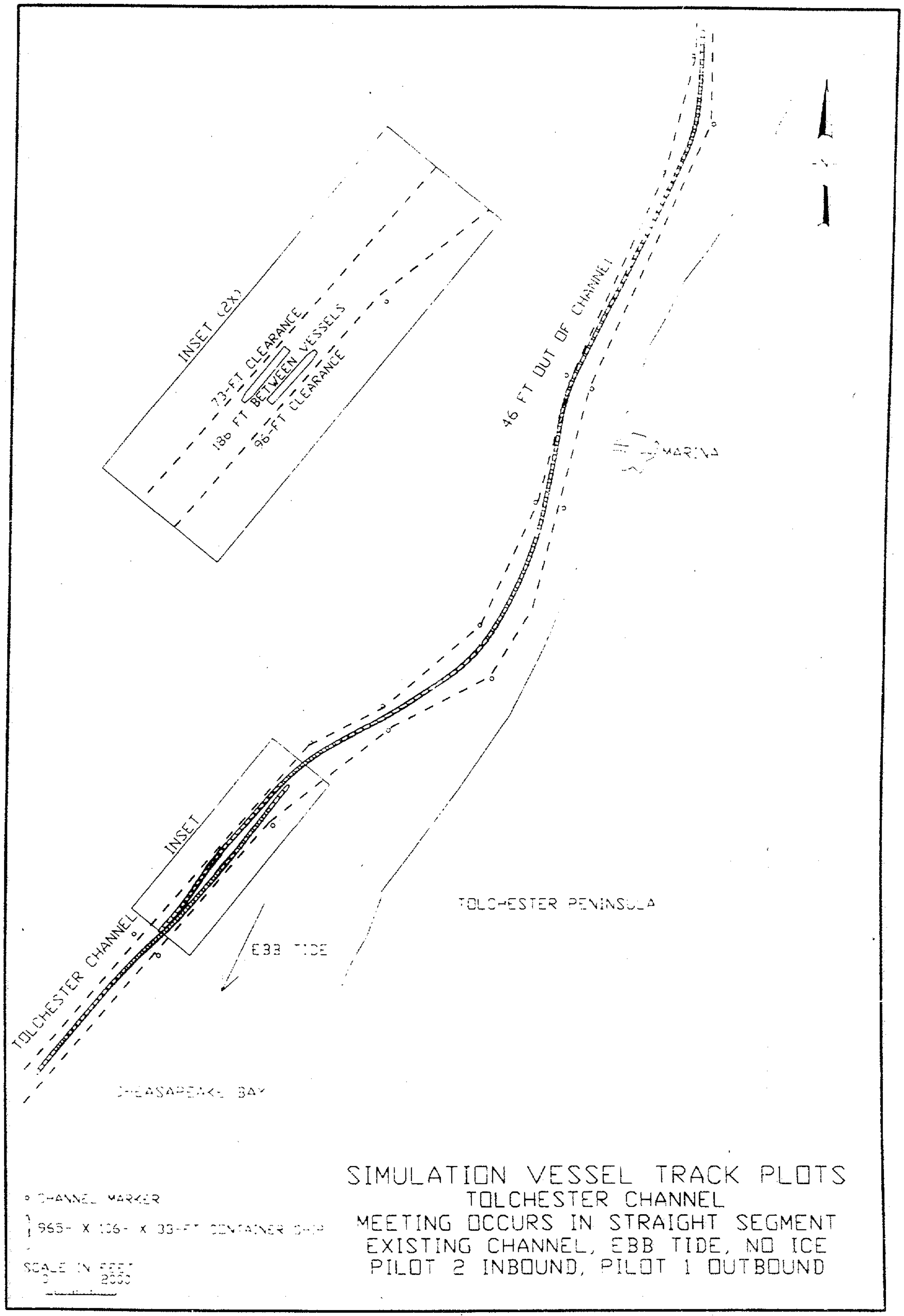
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

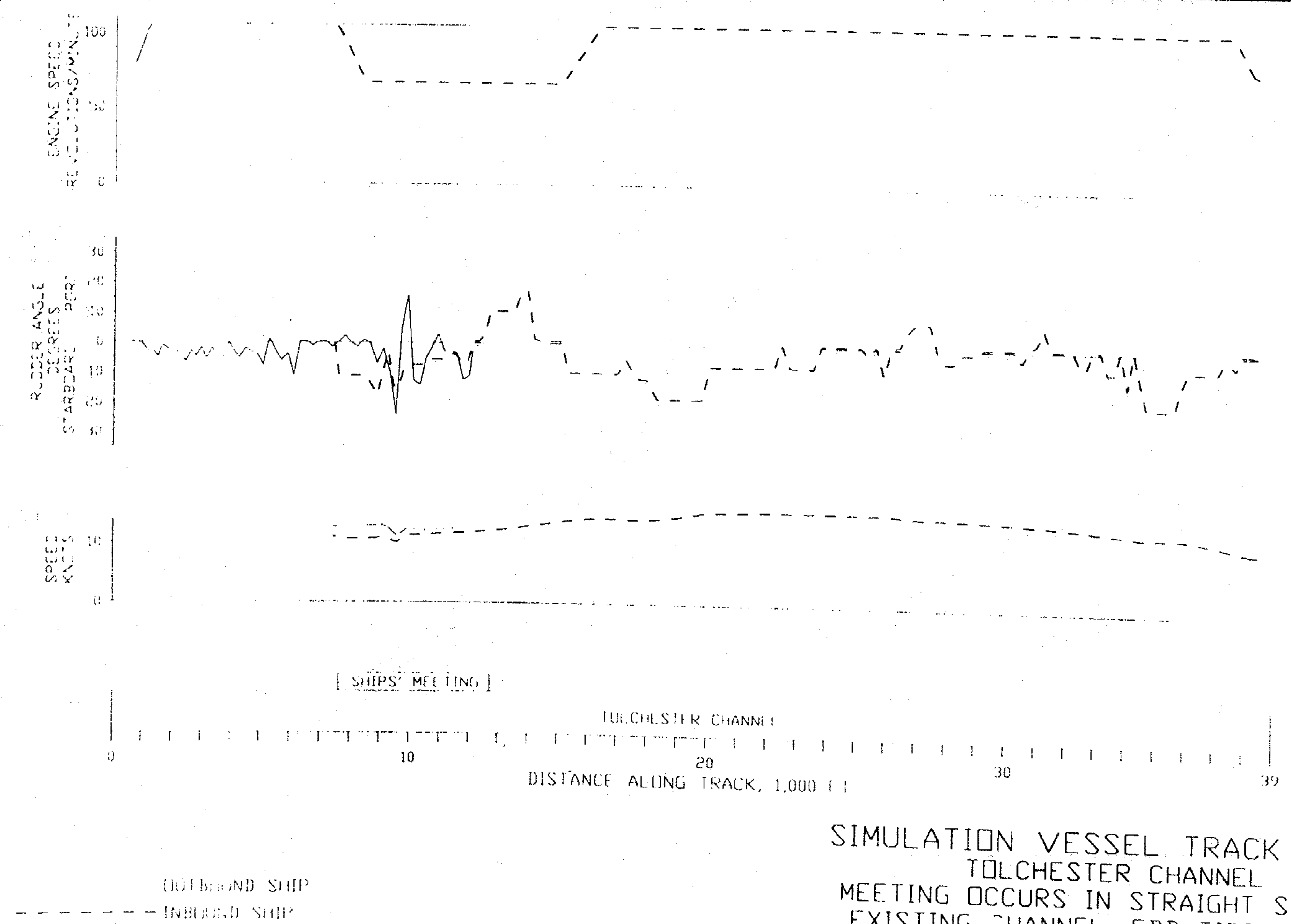
Plate 88

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

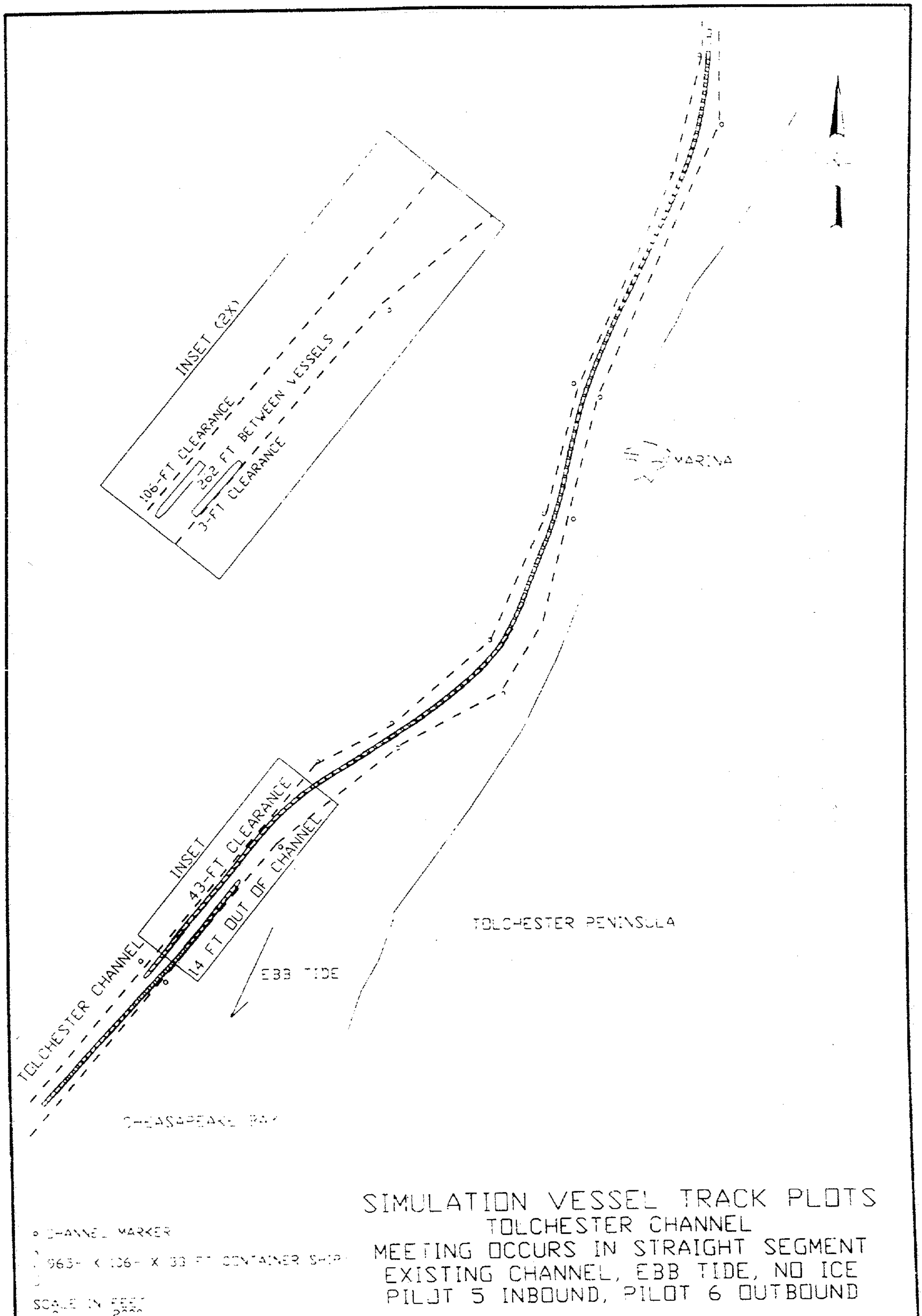
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

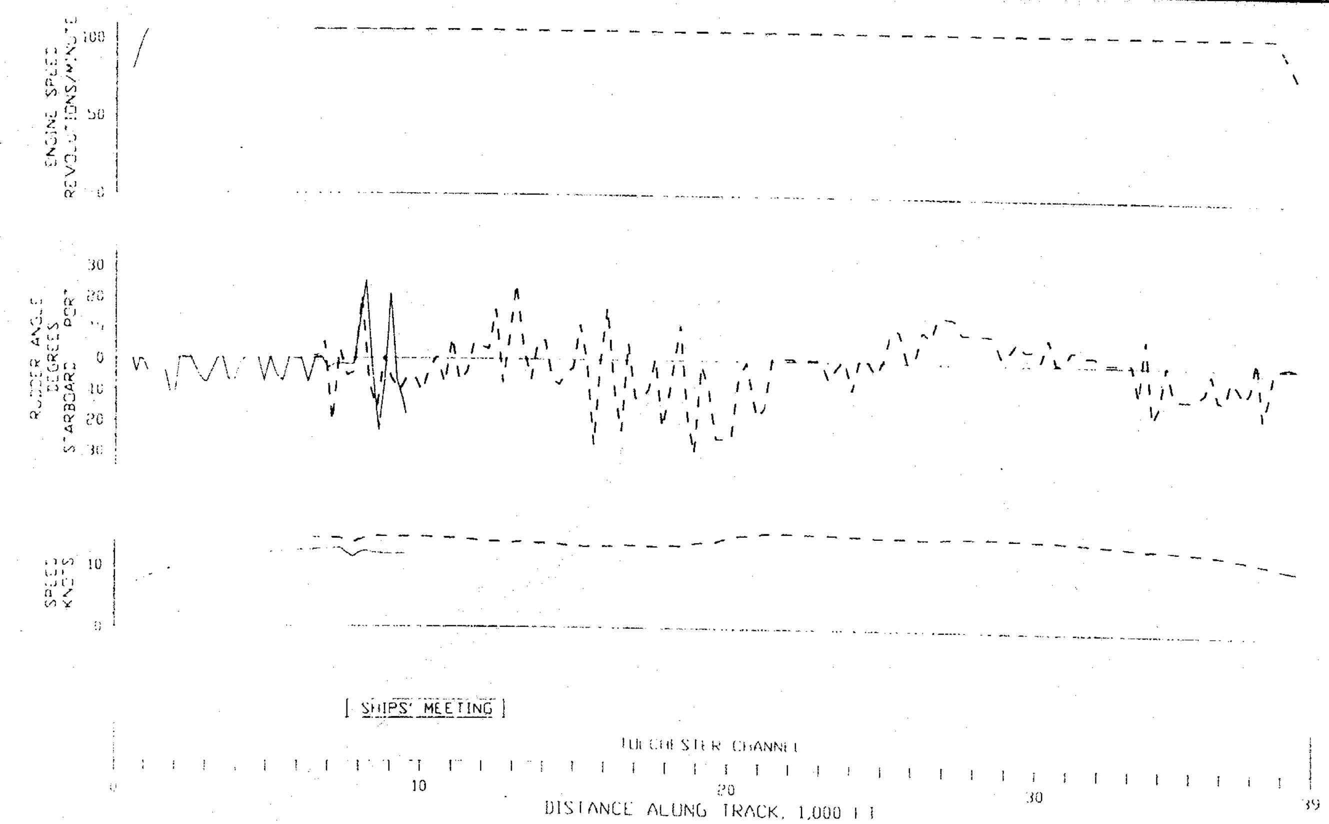
Plate 90

PRELIMINARY



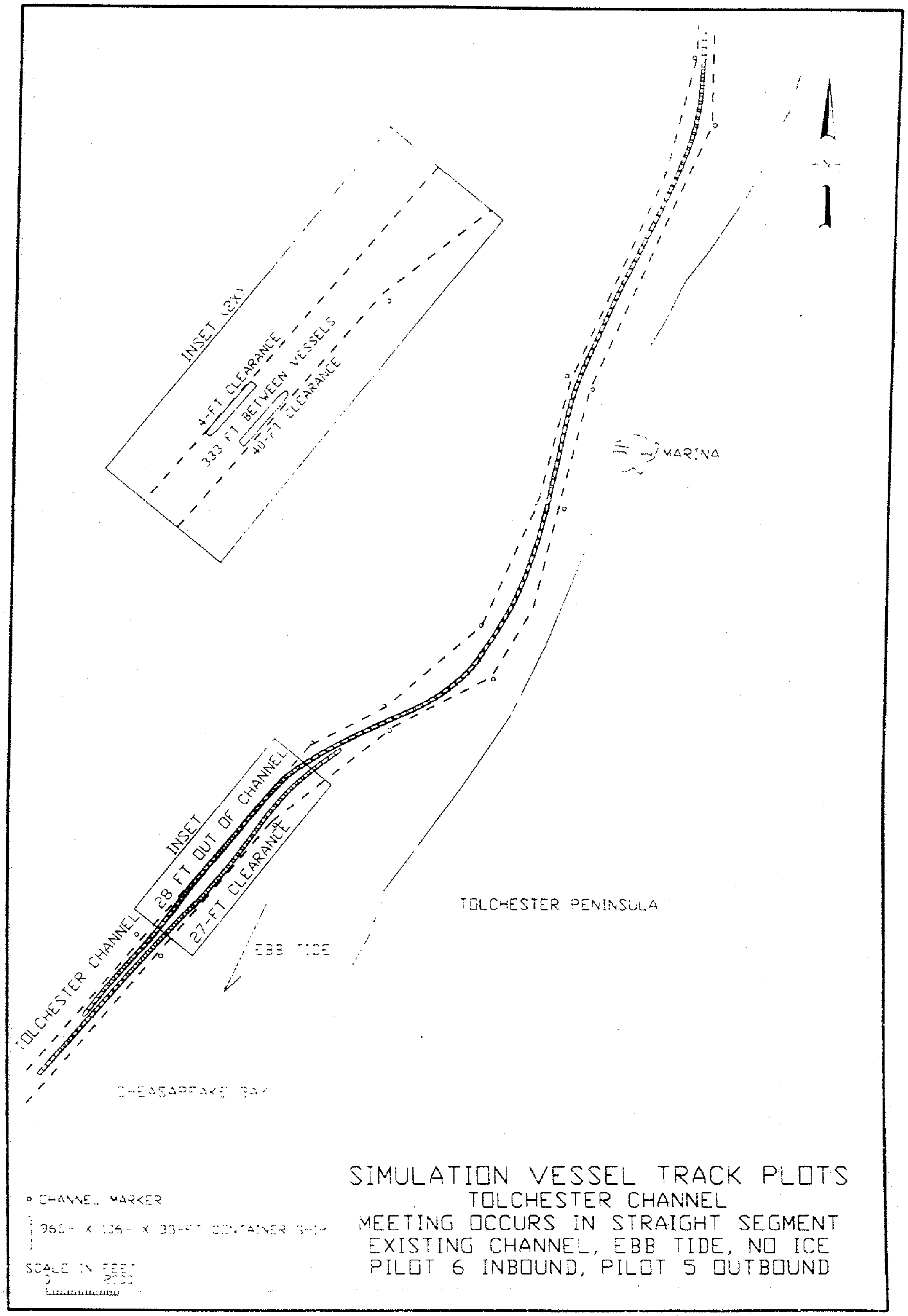
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

PRELIMINARY

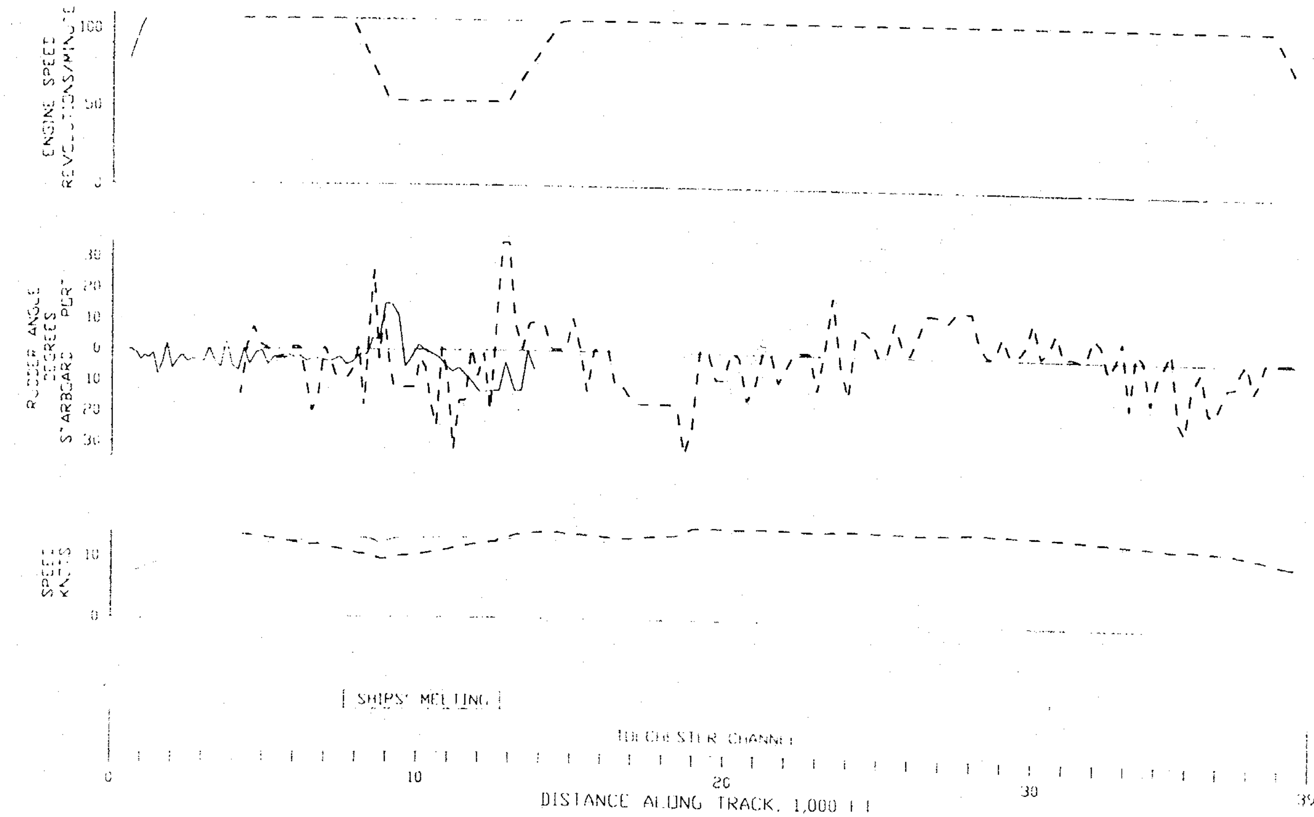


SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, E3B TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

PRELIMINARY



PRELIMINARY

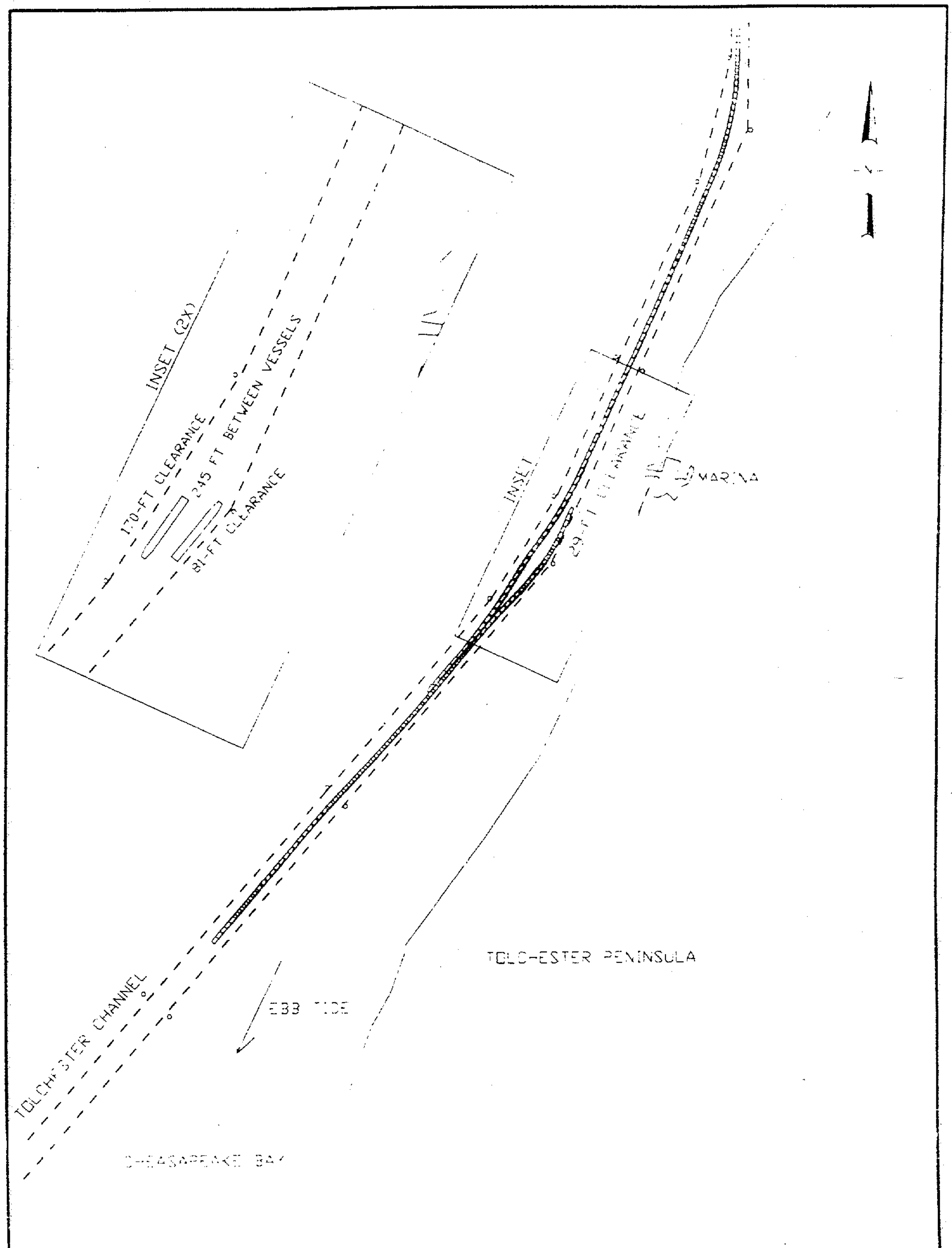


OUTBOUND SHIP
INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 94

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

PRELIMINARY

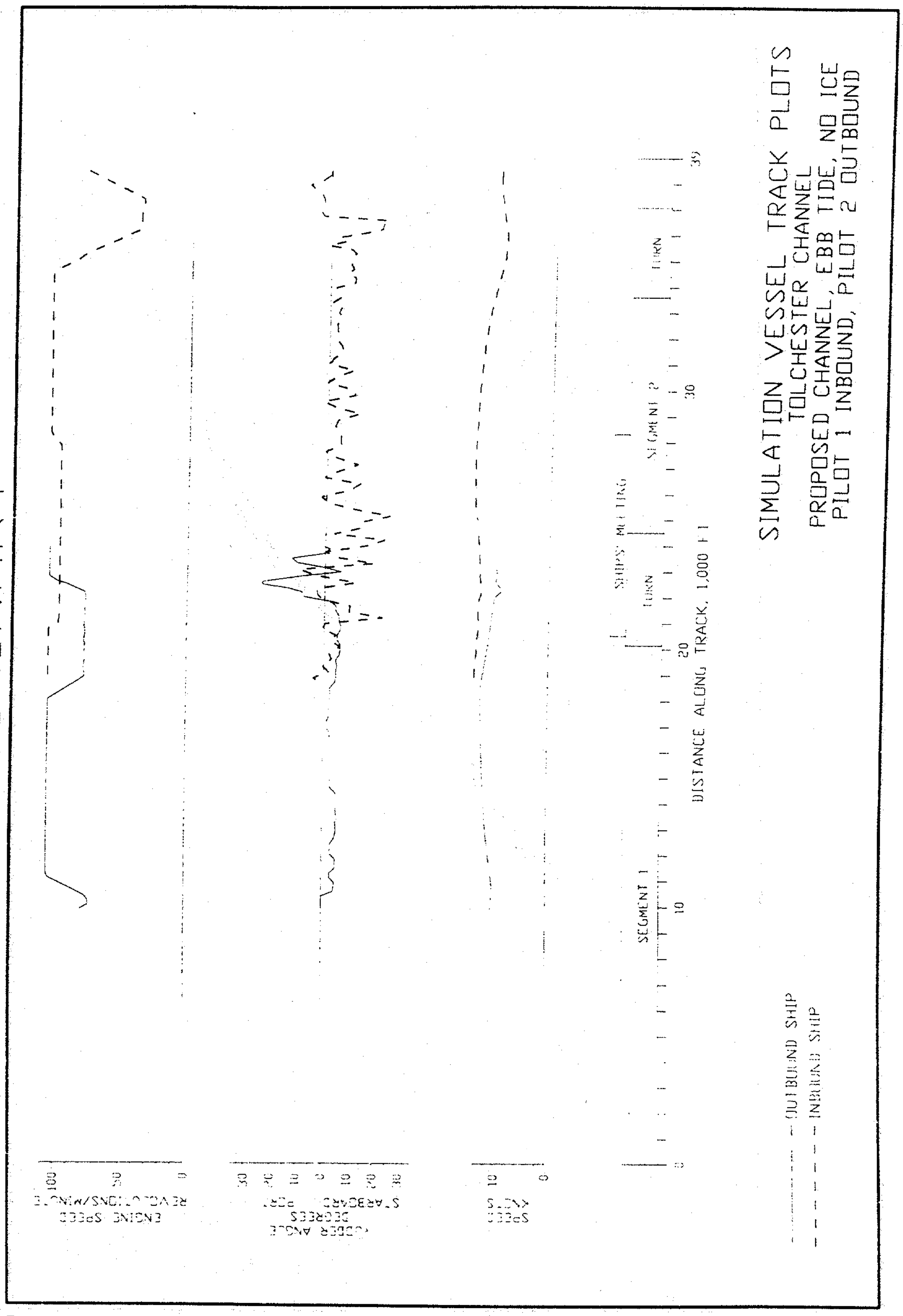
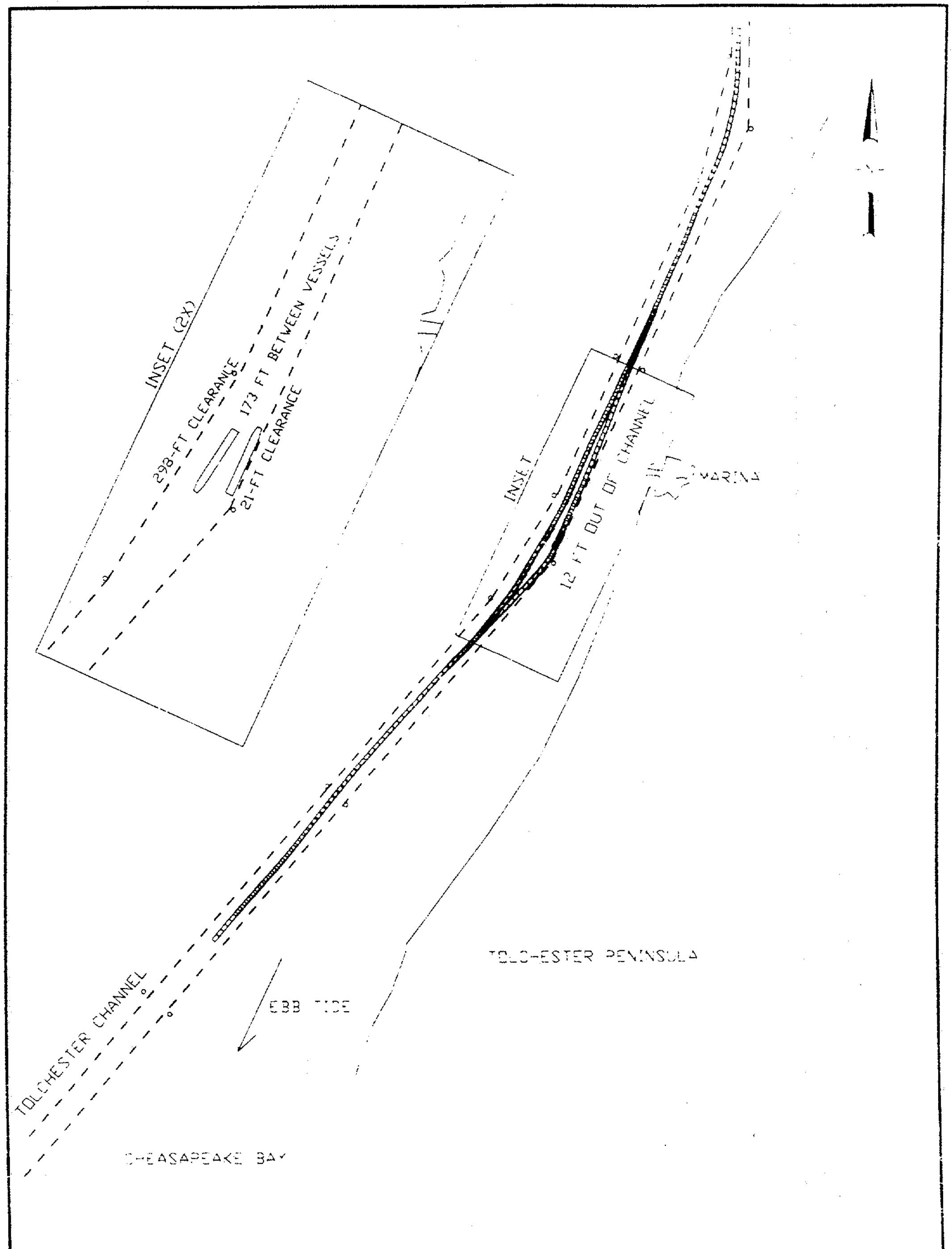


Plate 96

PRELIMINARY

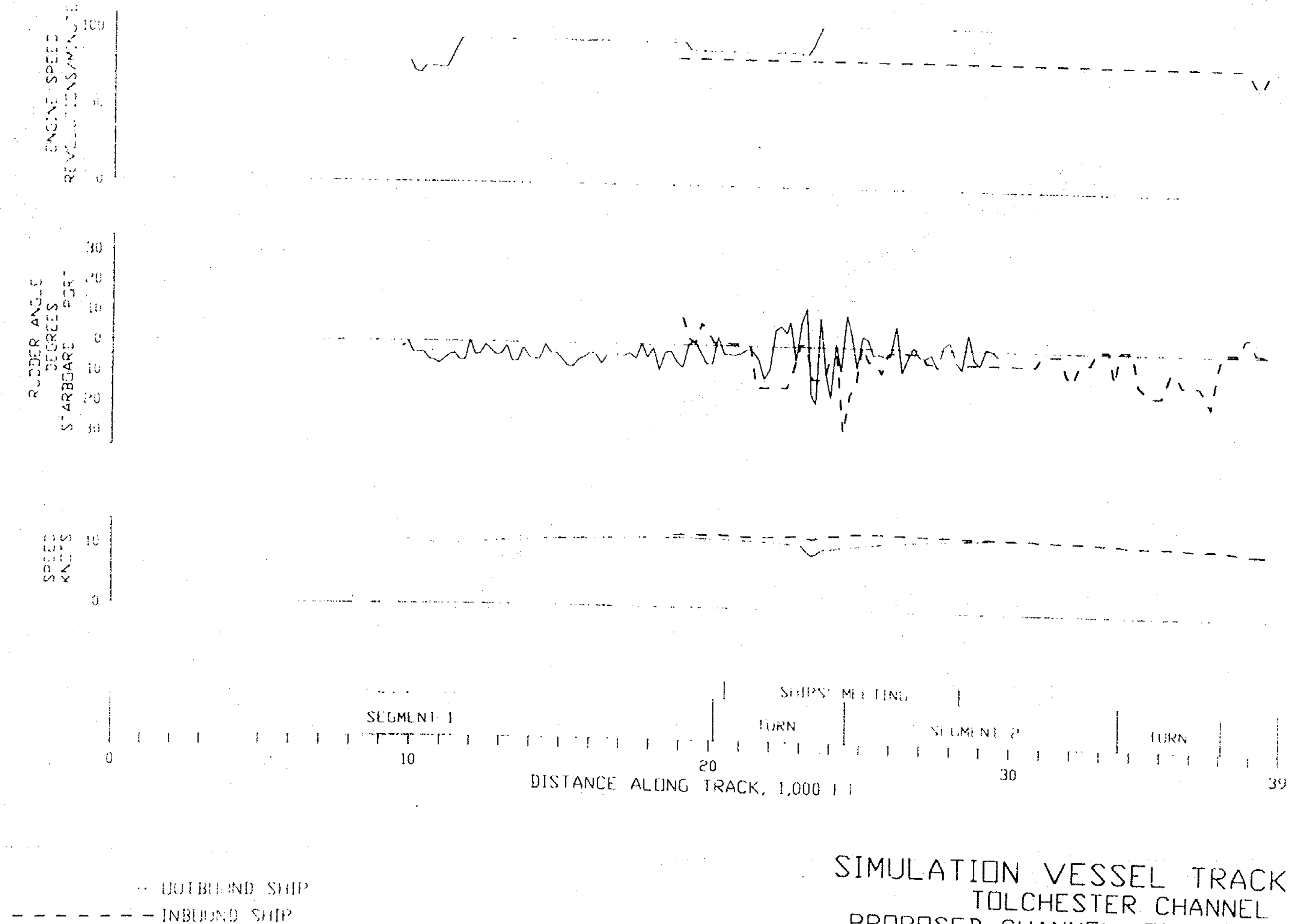


CHANNEL MARKER

SCALE IN FEET

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

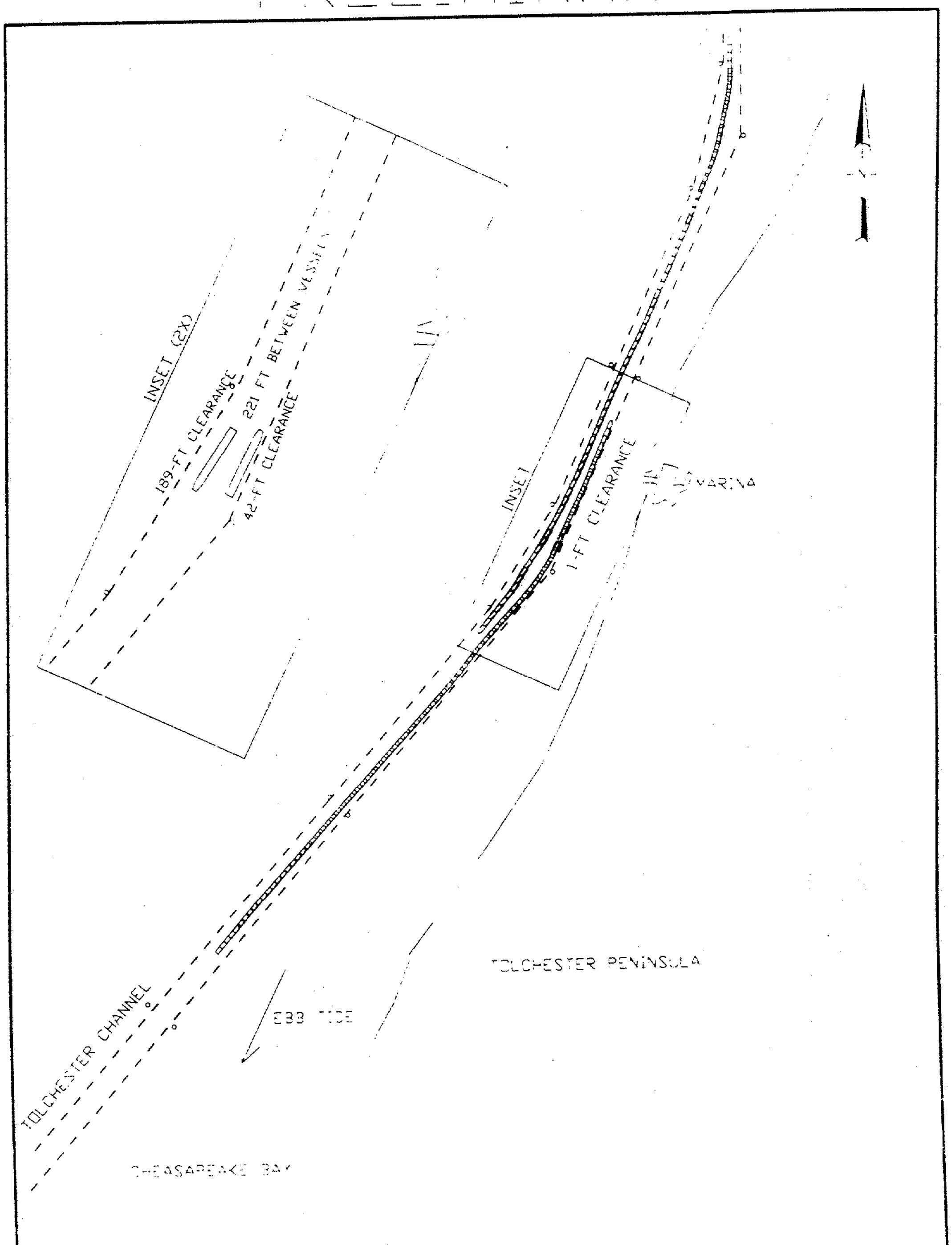
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

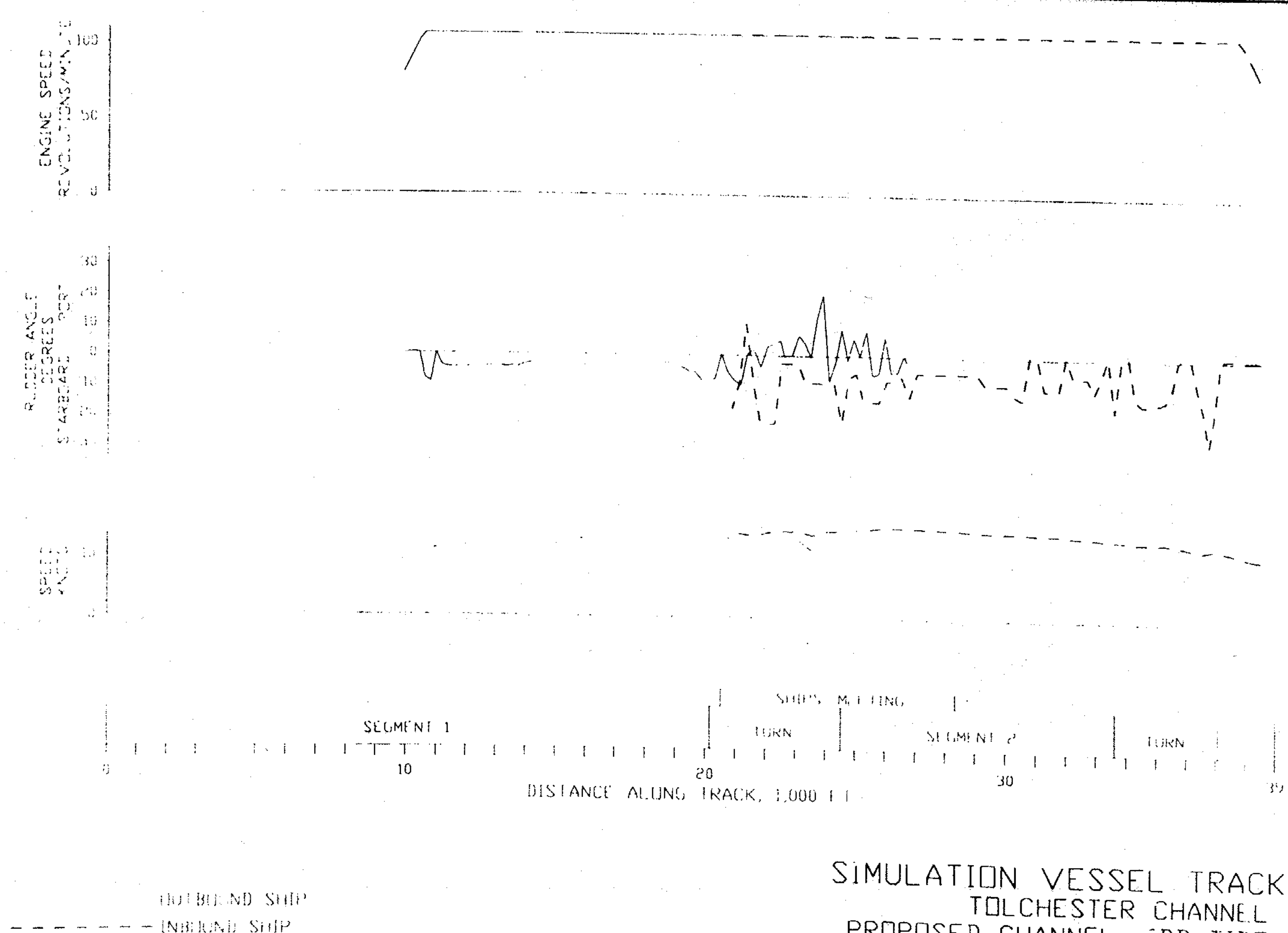
Plate 98

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

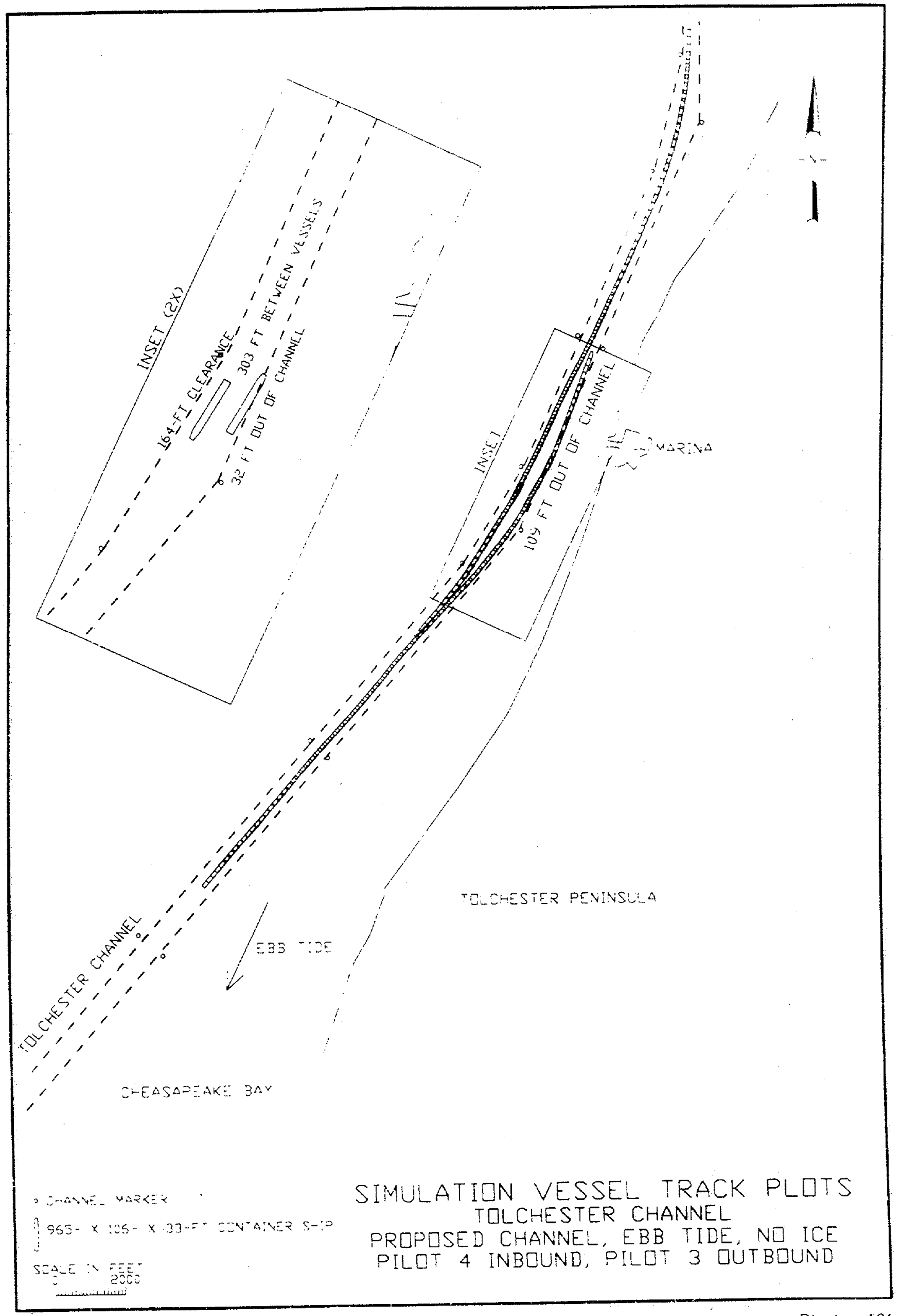
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

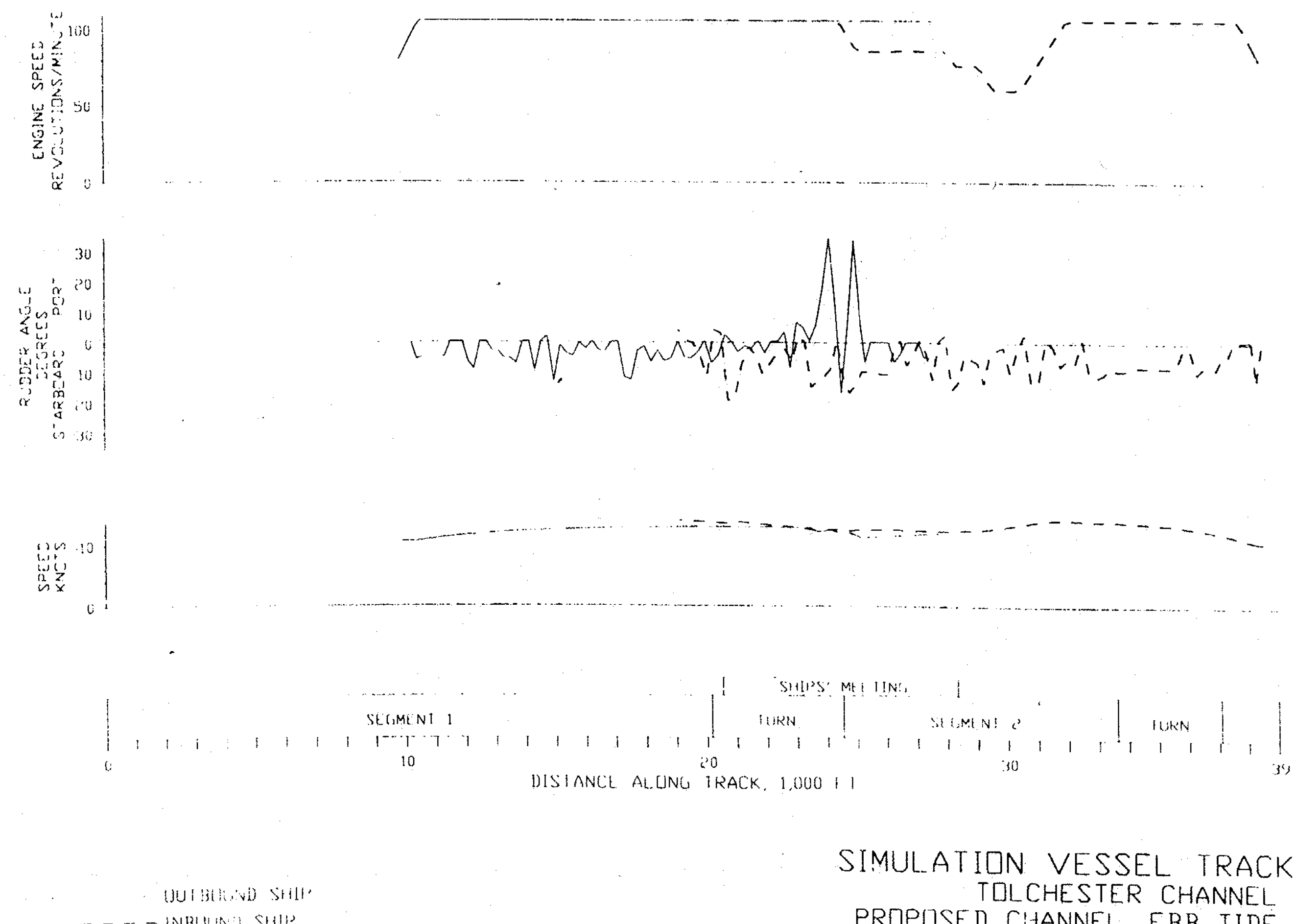
Plate 100

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

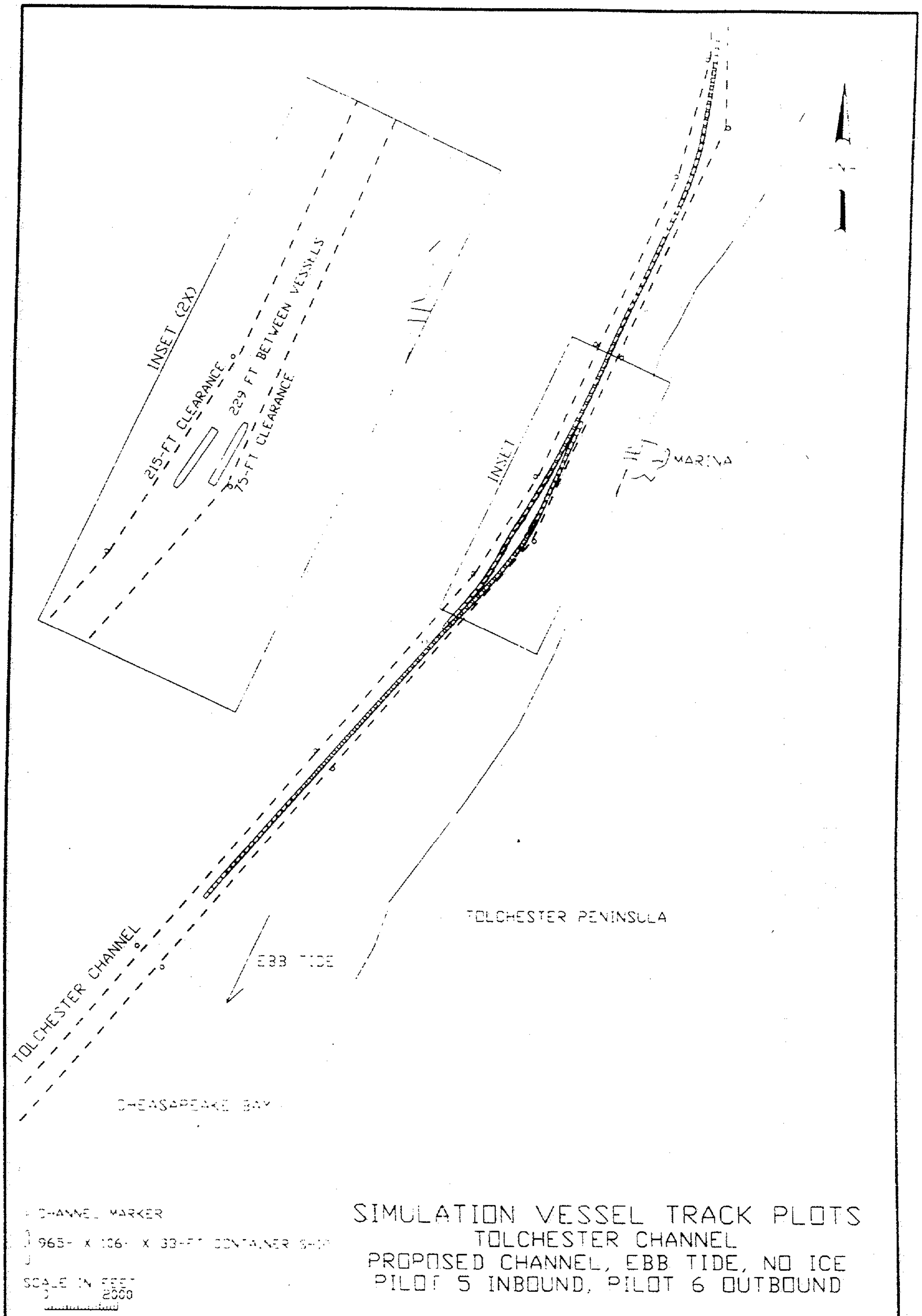
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

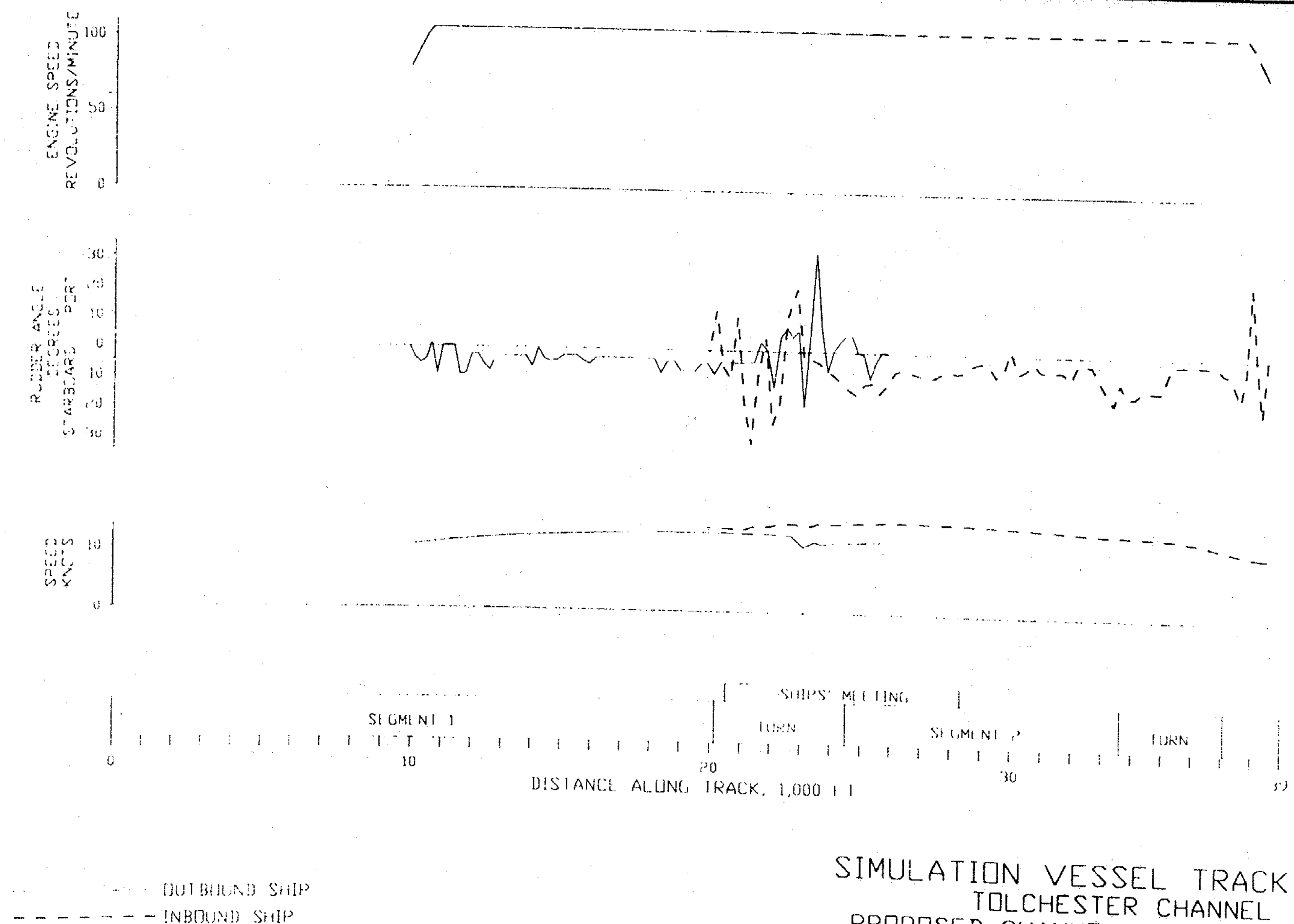
Plate 102

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

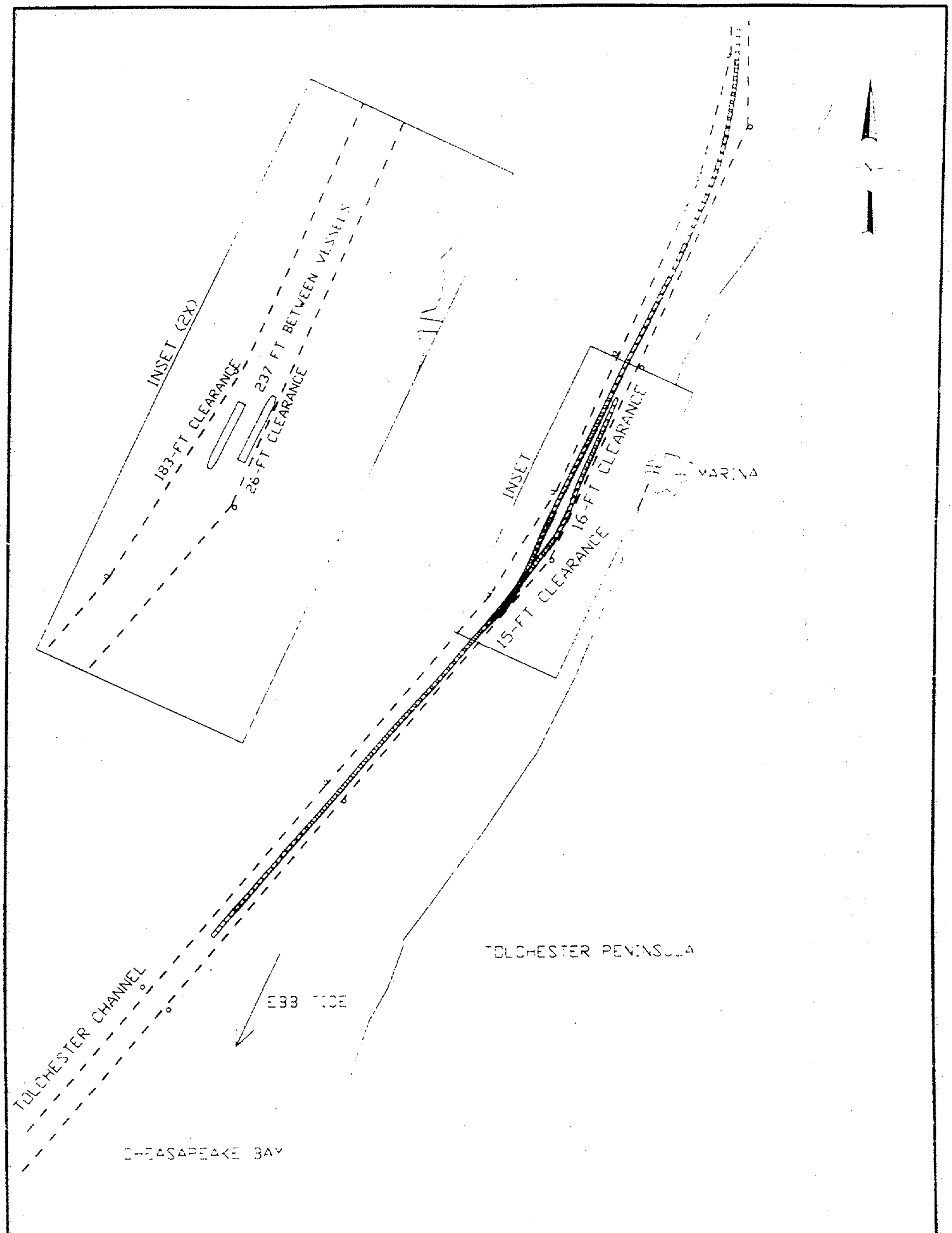
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 104

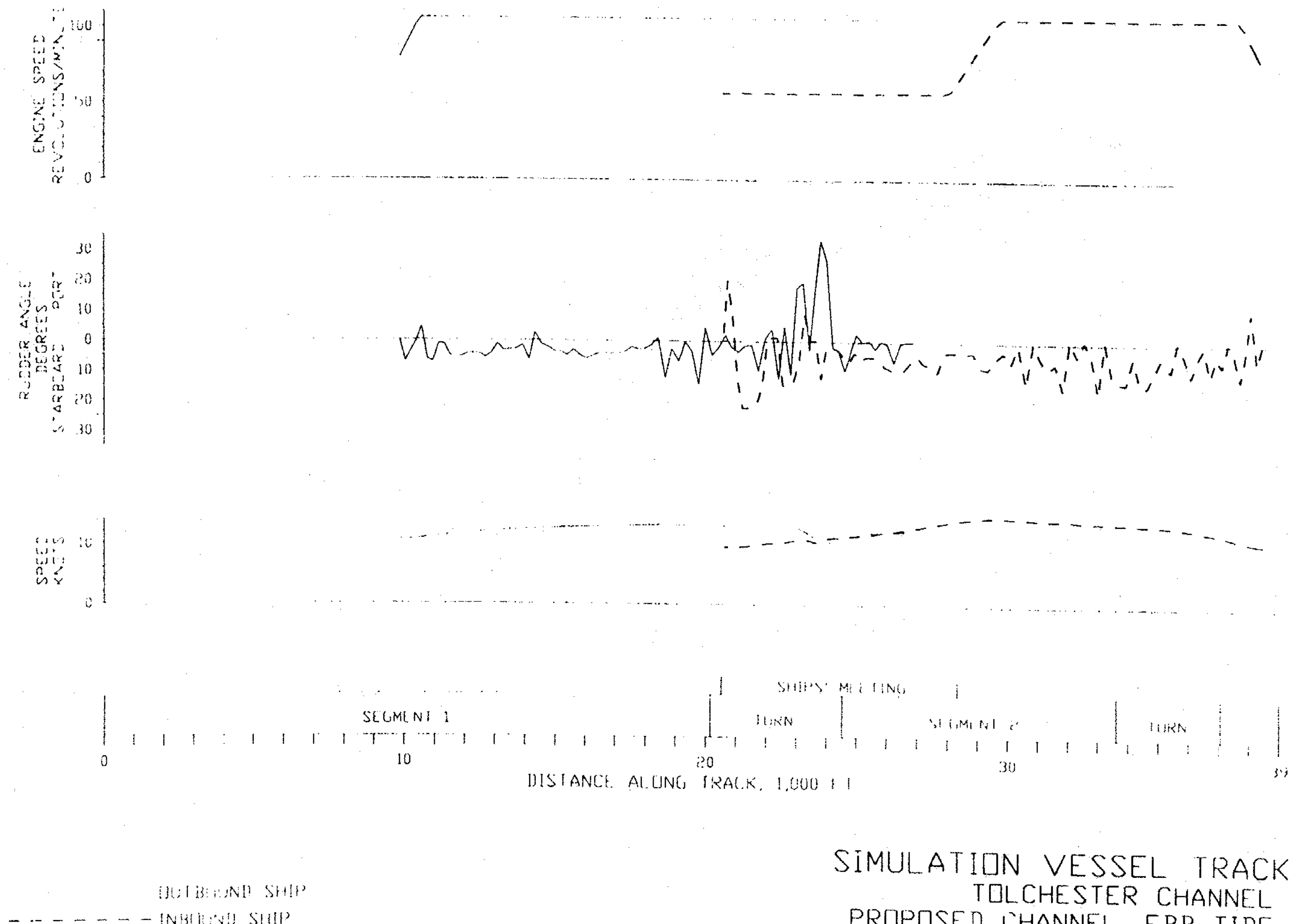
PRELIMINARY



CHANNEL MARKER
965-FT X 106-FT X 39-FT CONTAINER SHIP
SCALE IN FEET
0 2000

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

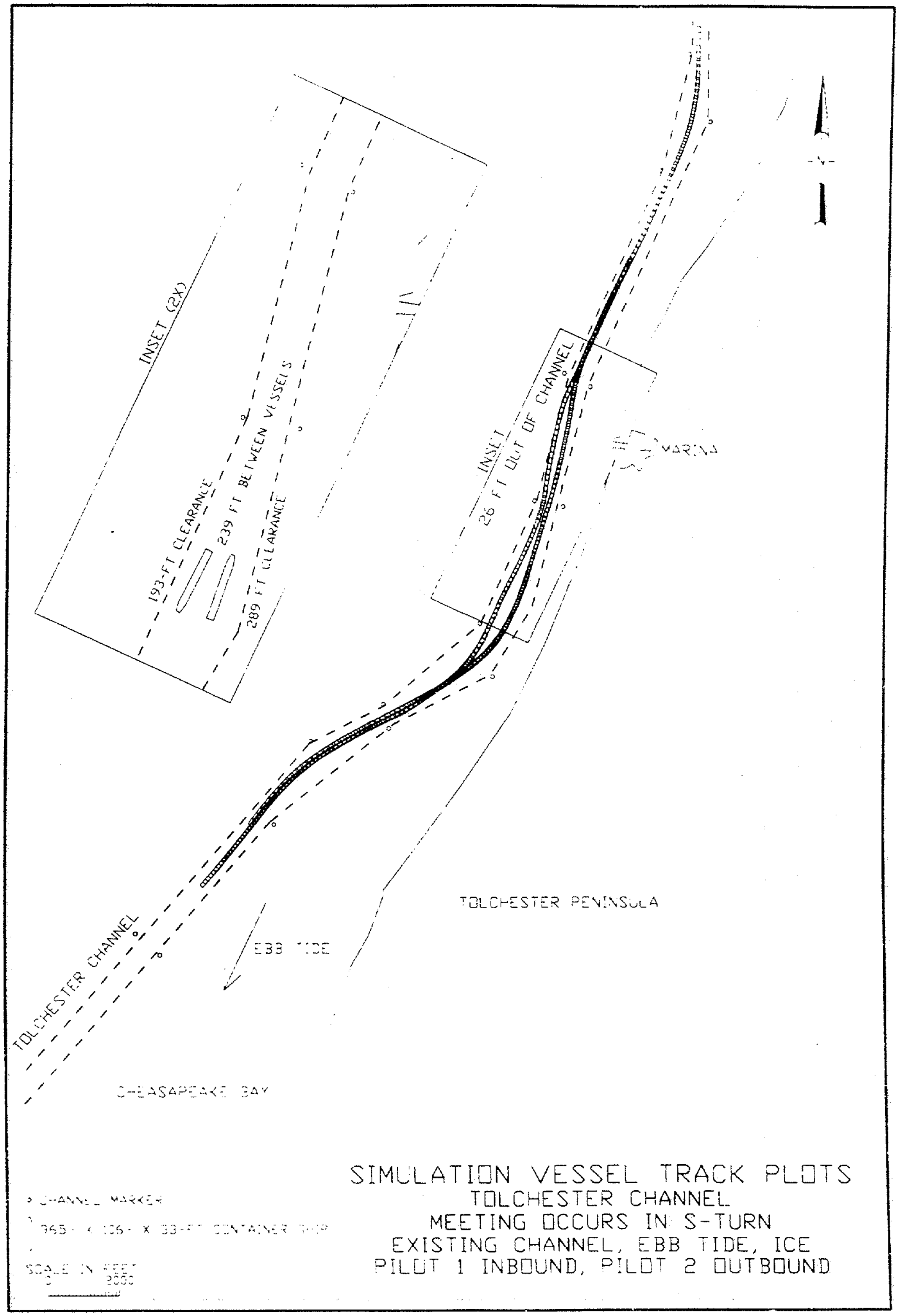
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

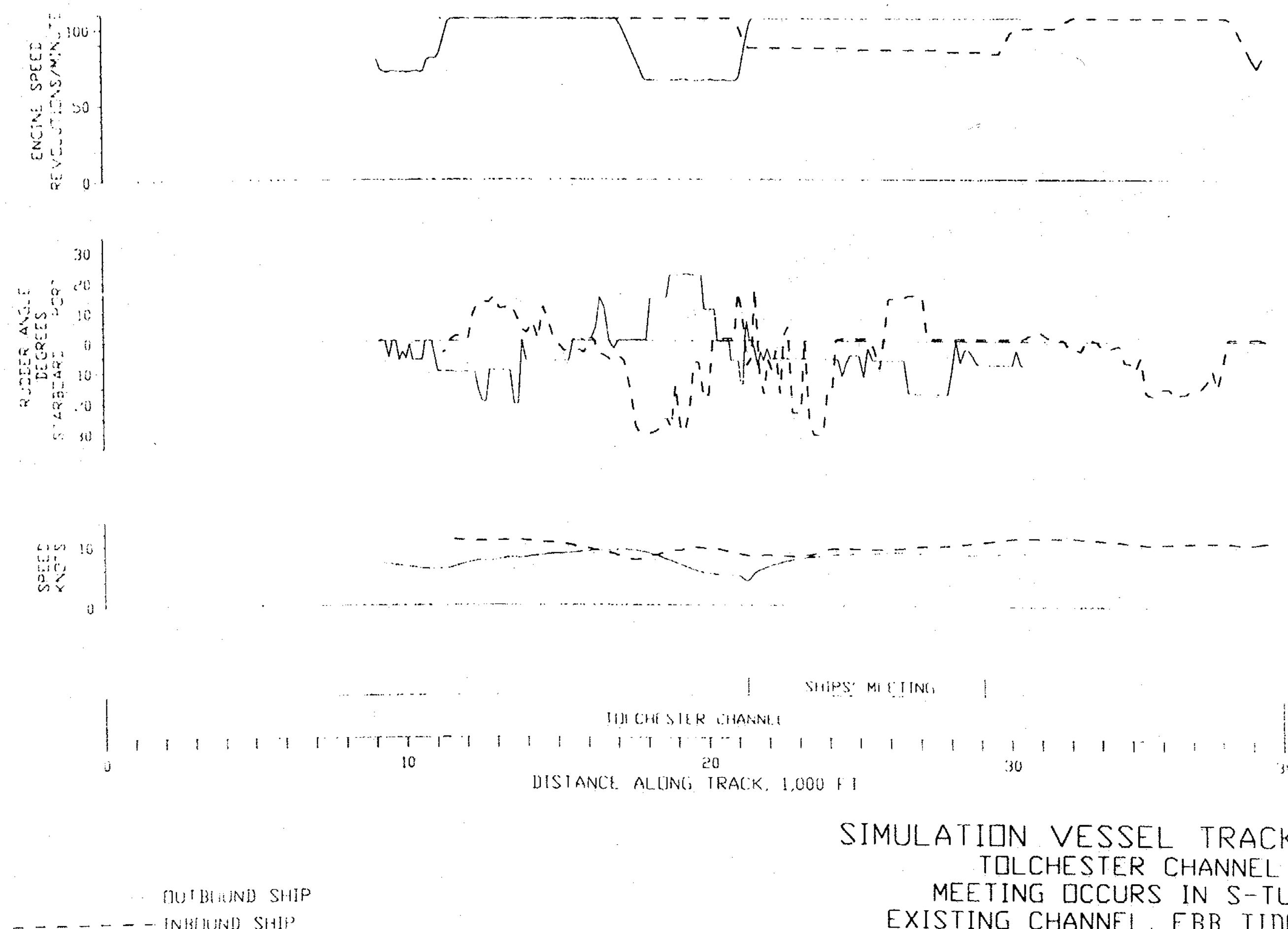
Plate 106

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

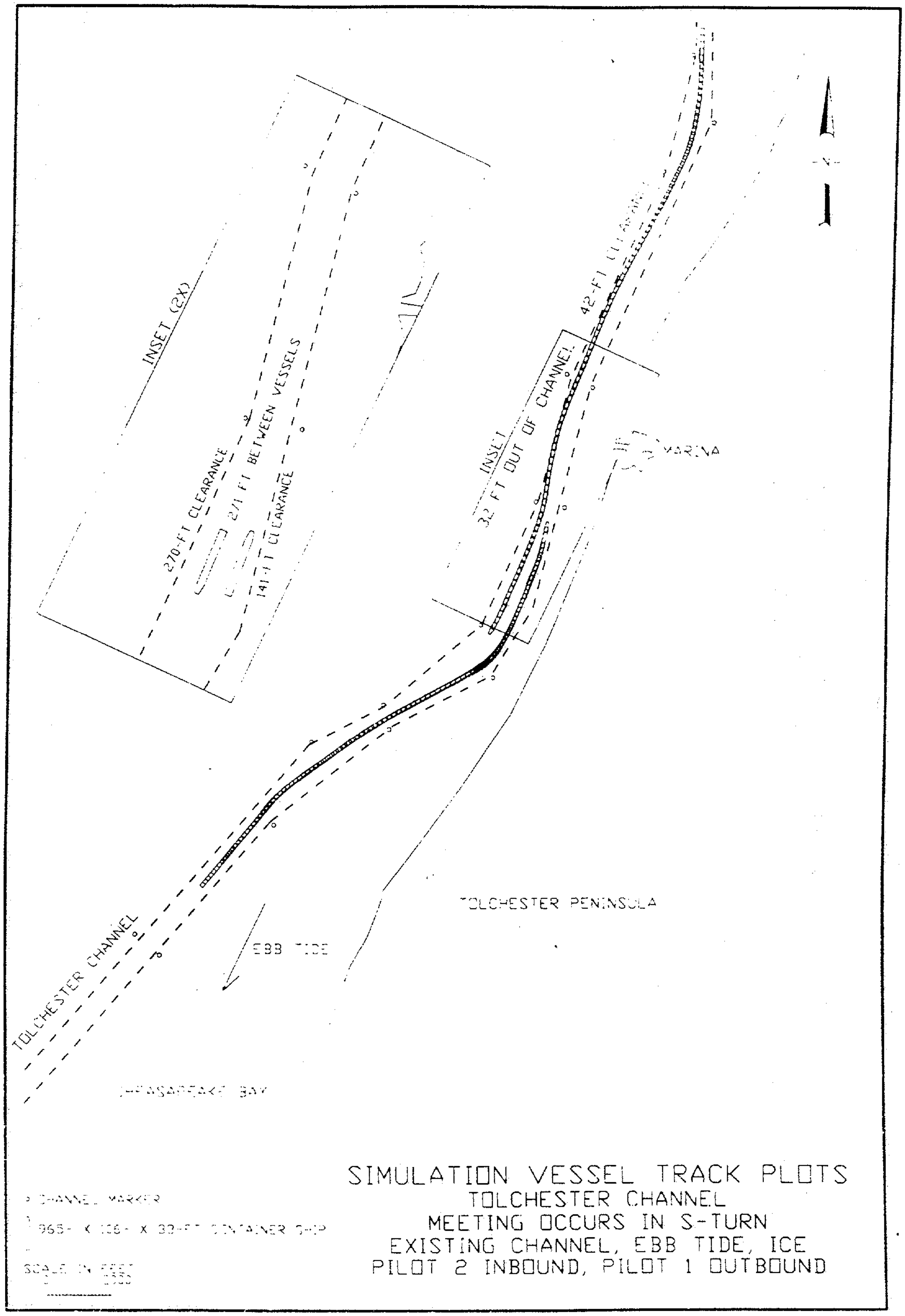
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

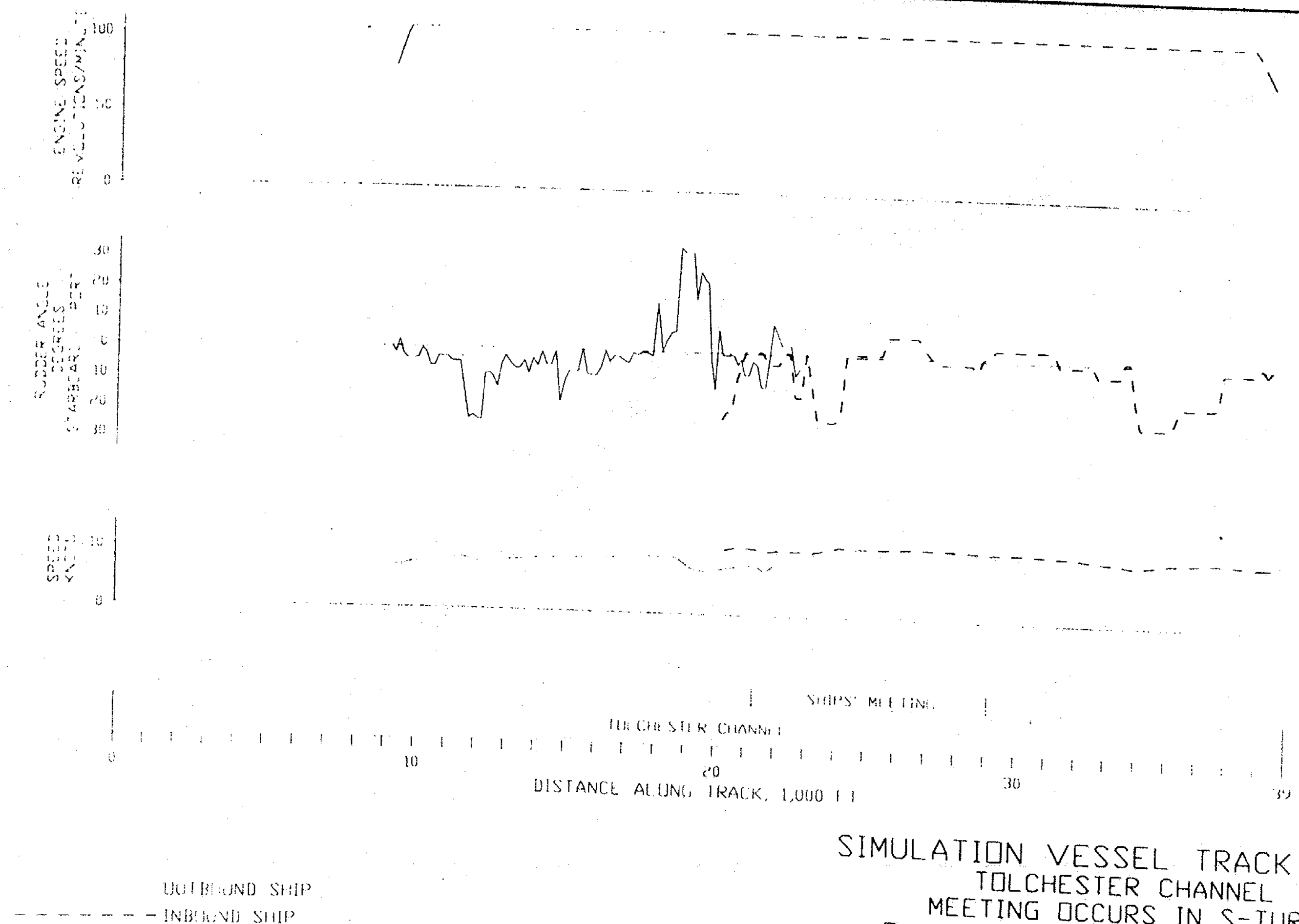
Plate 108

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

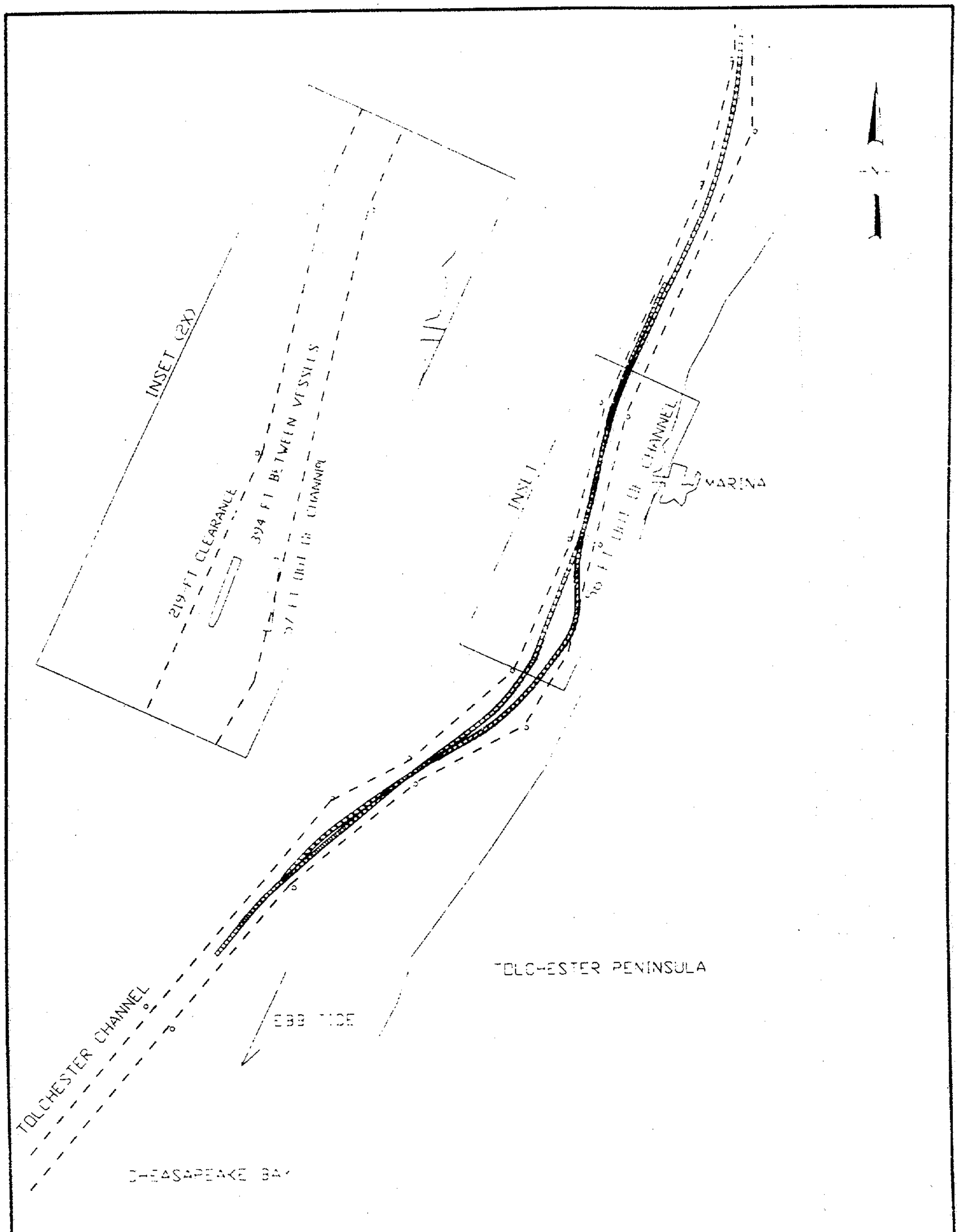
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 110

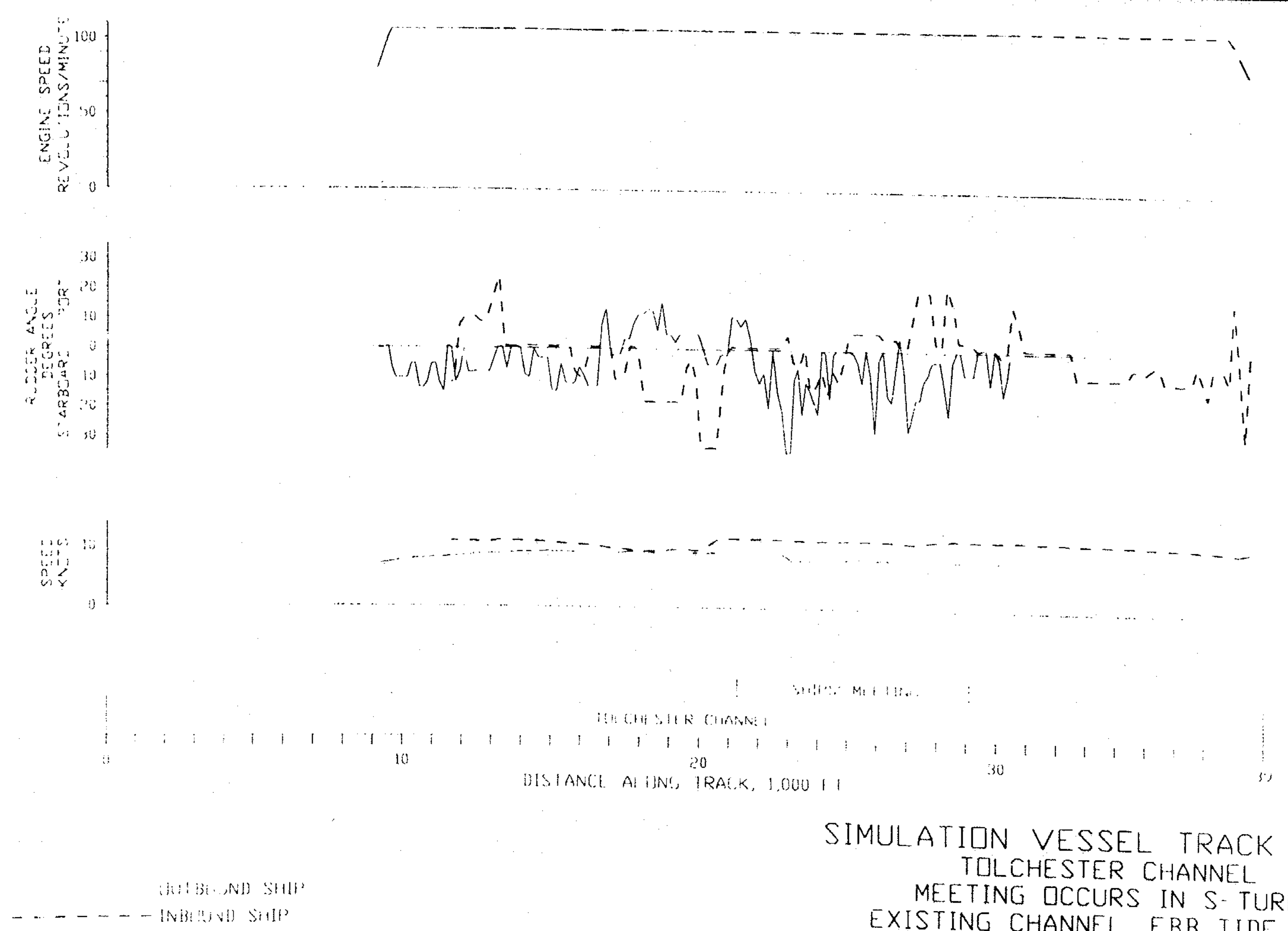
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 111

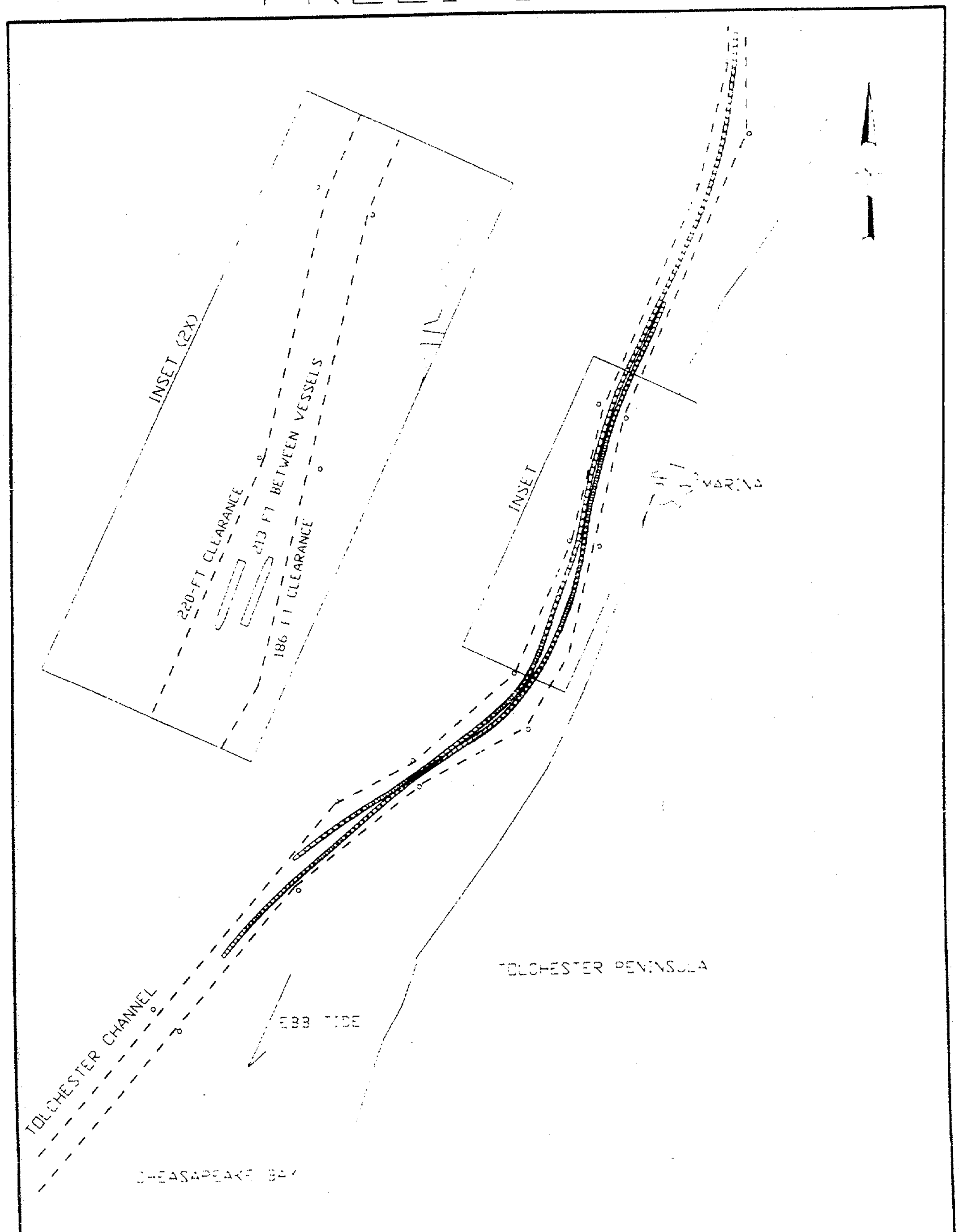
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

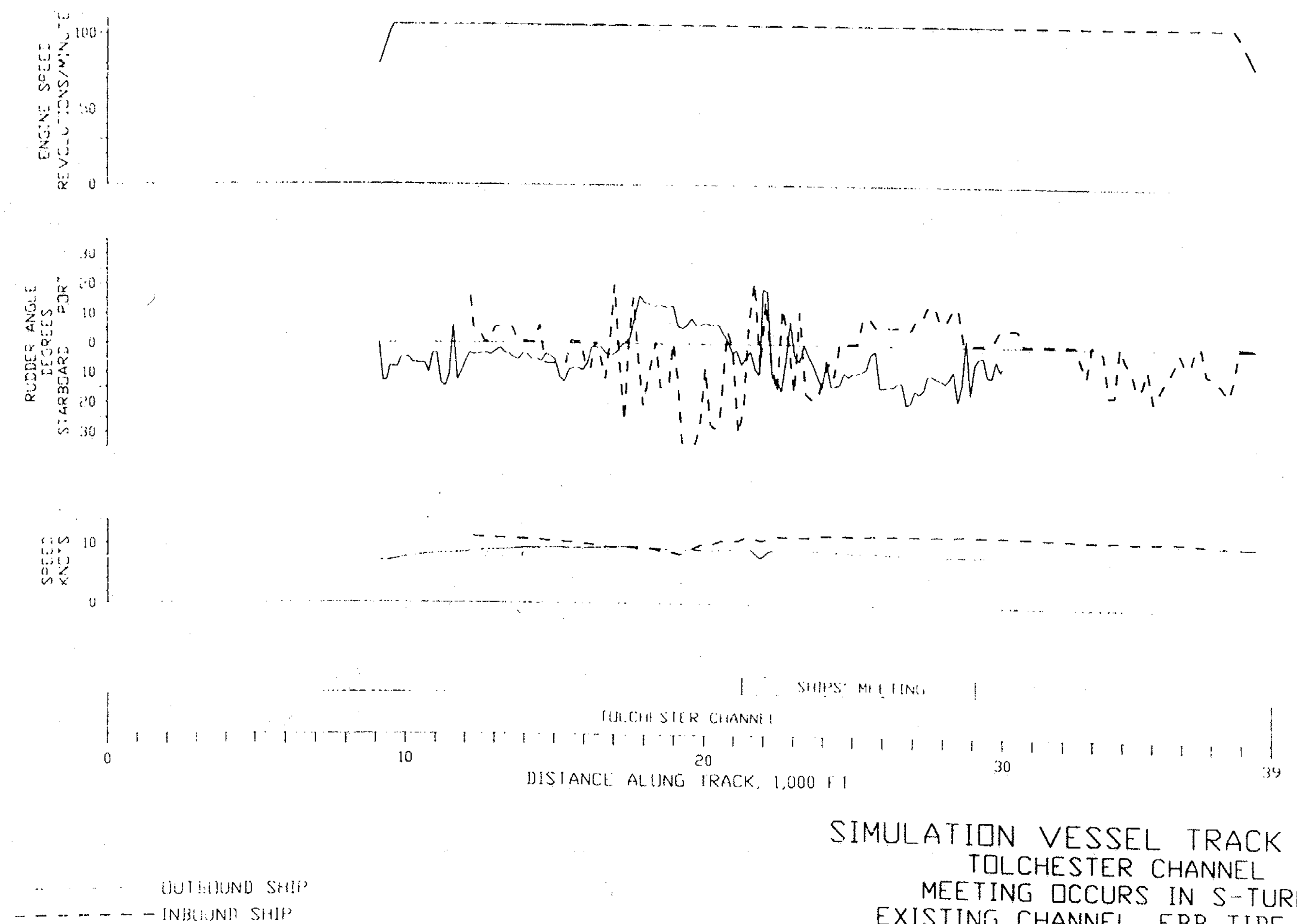
Plate 112

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

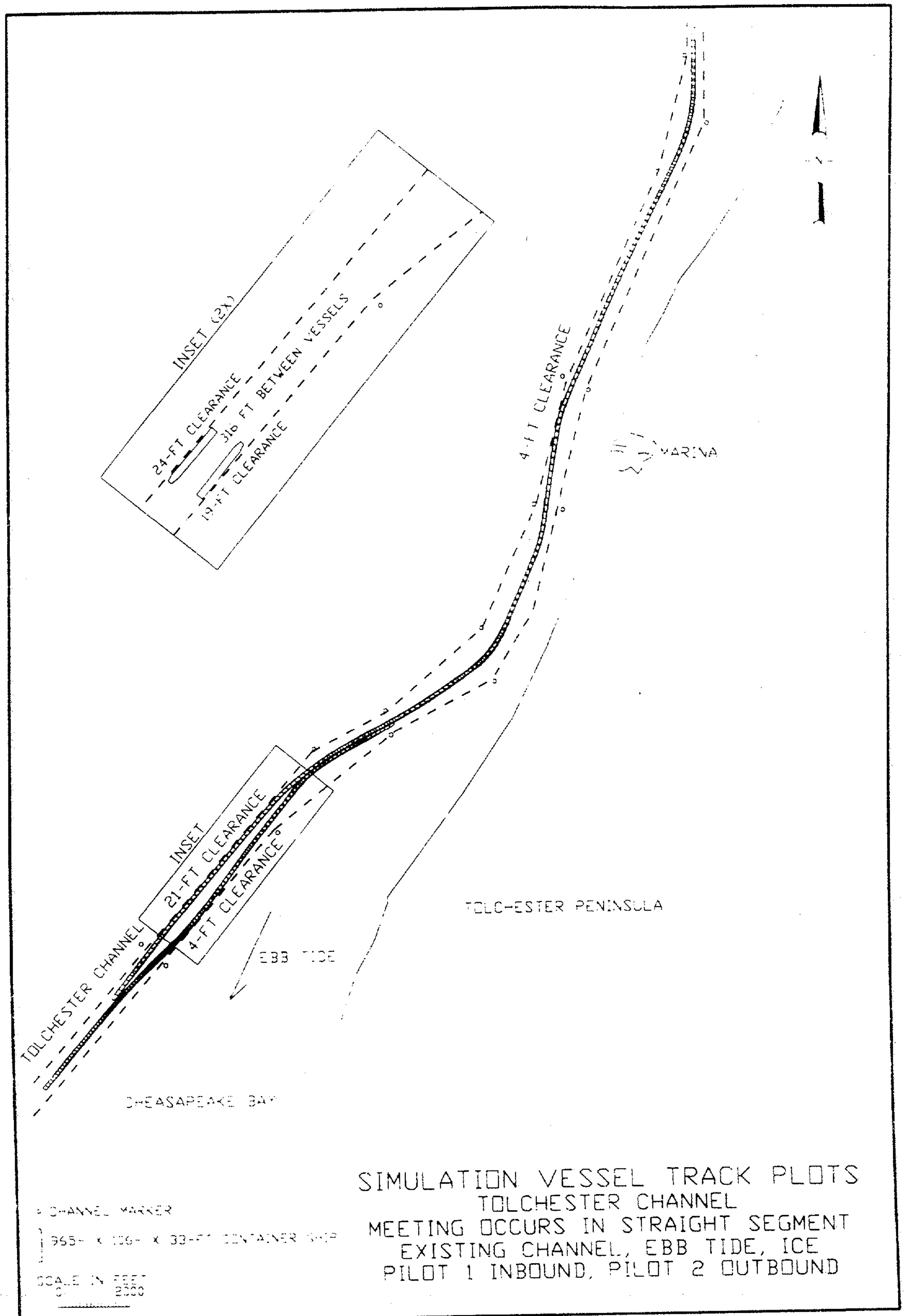
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

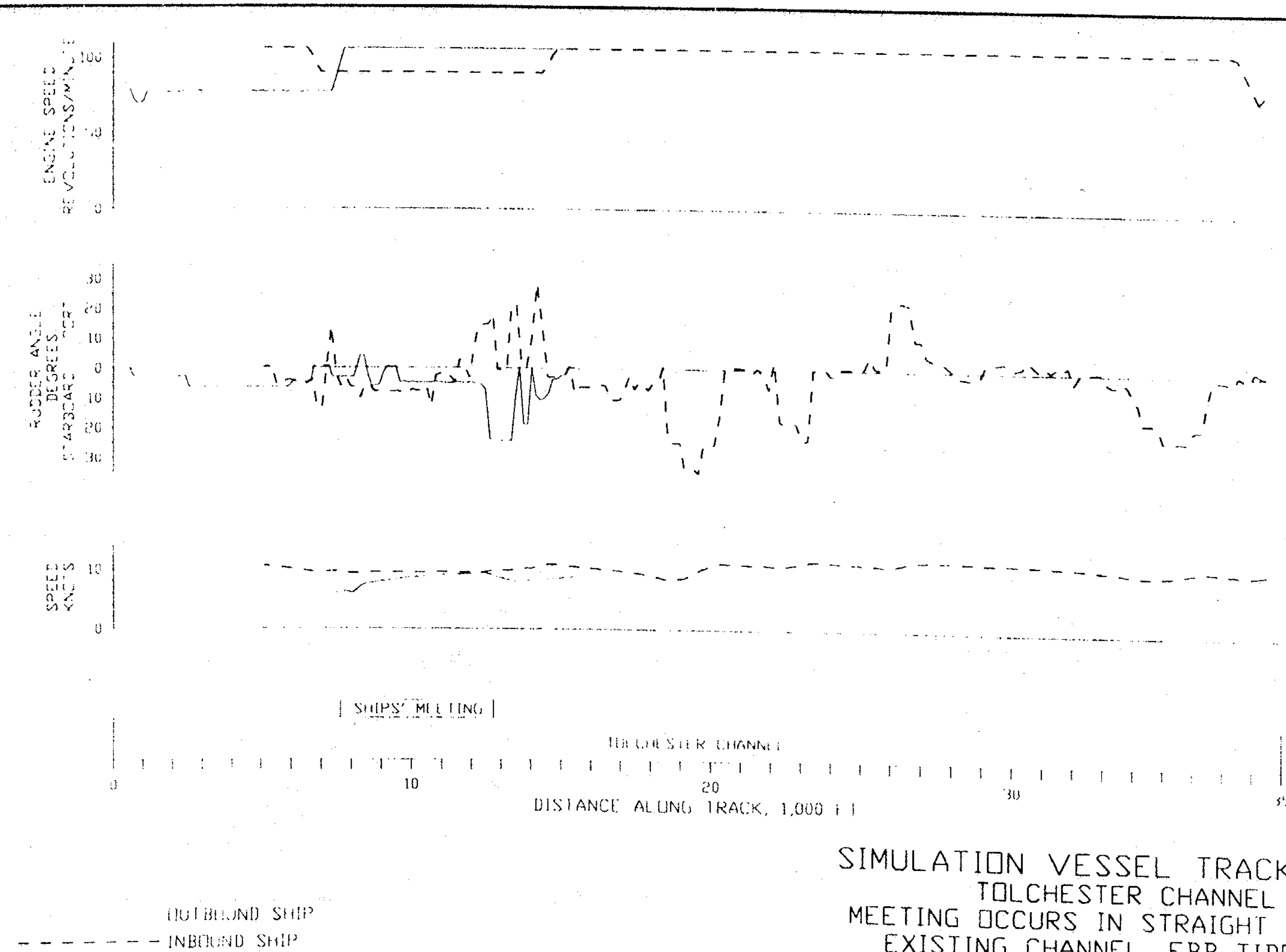
Plate 114

PRELIMINARY



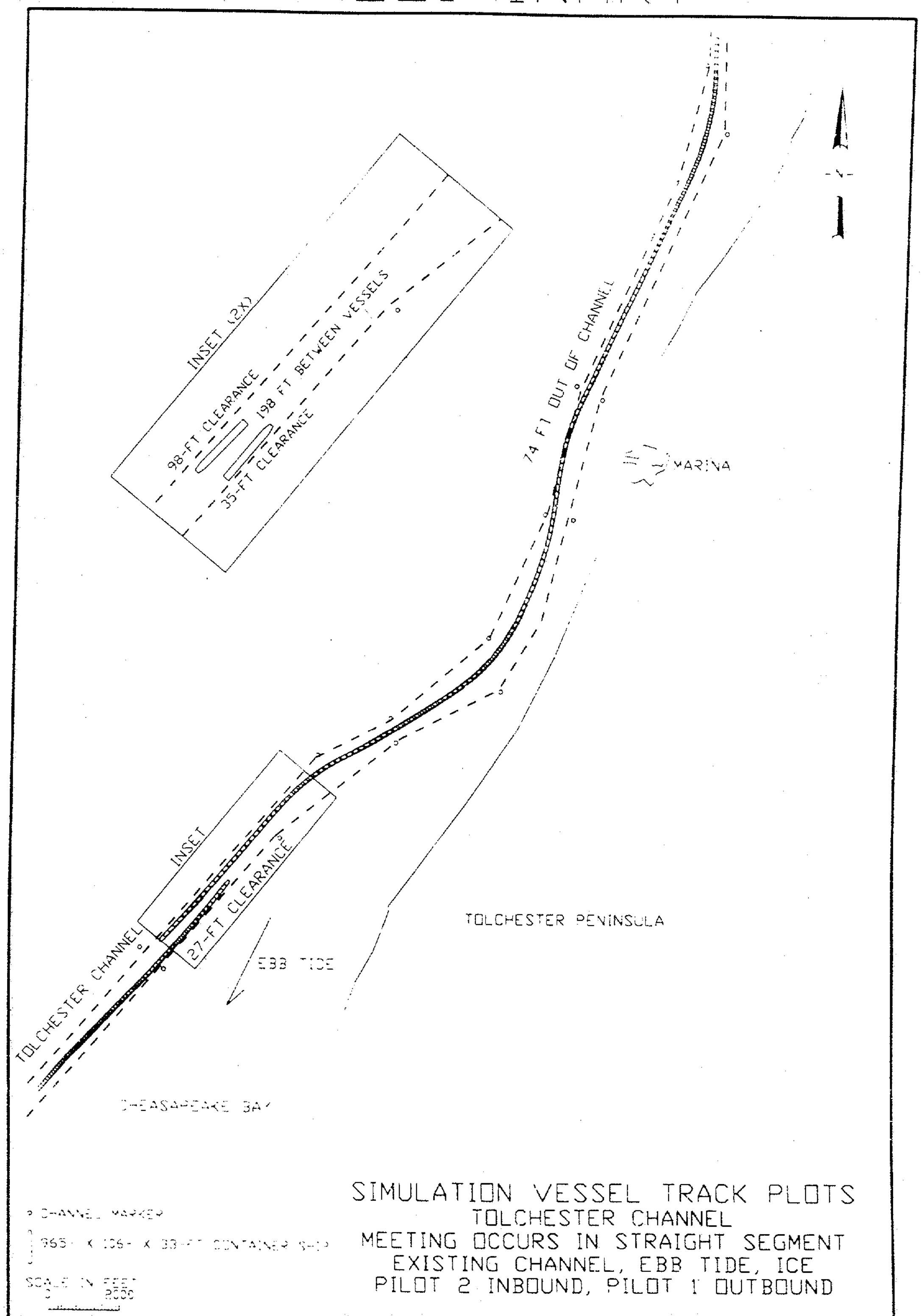
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

PRELIMINARY

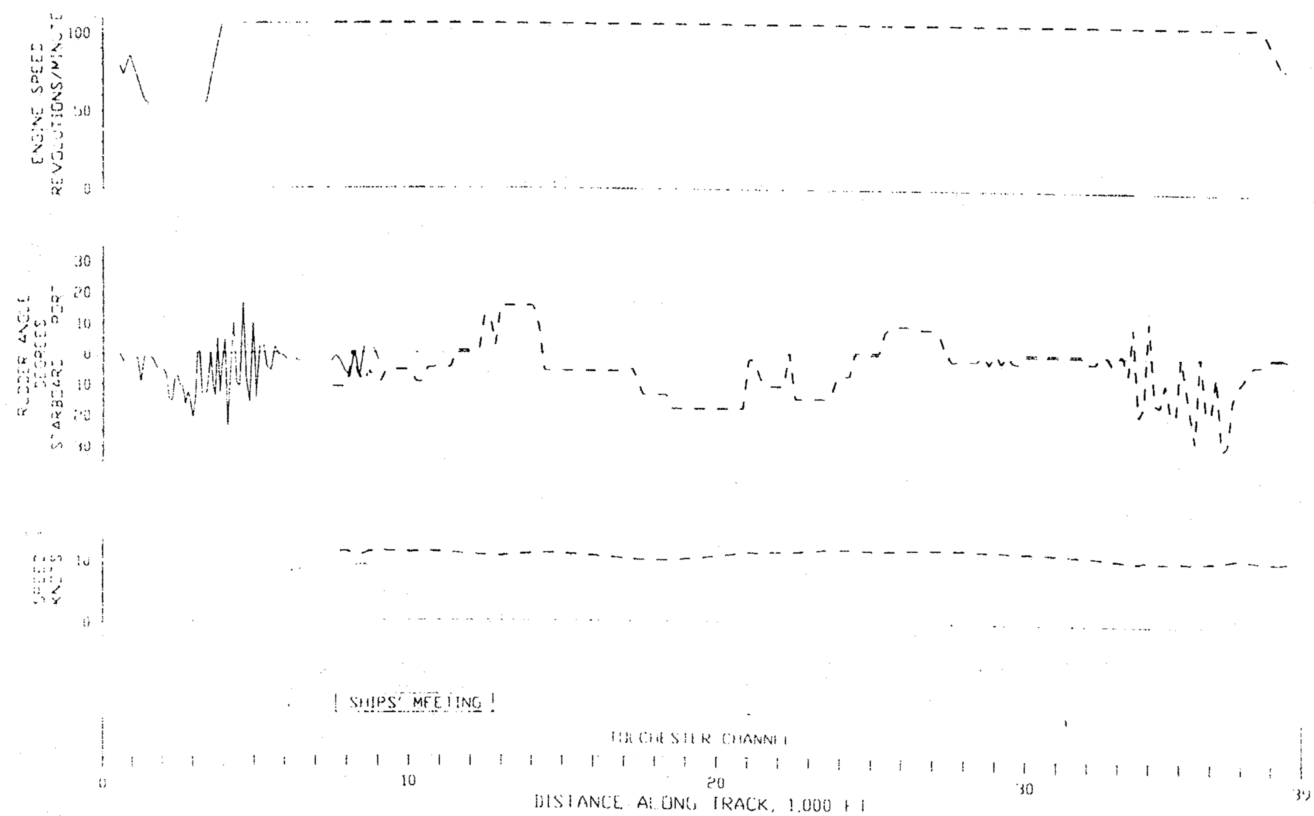


SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

PRELIMINARY



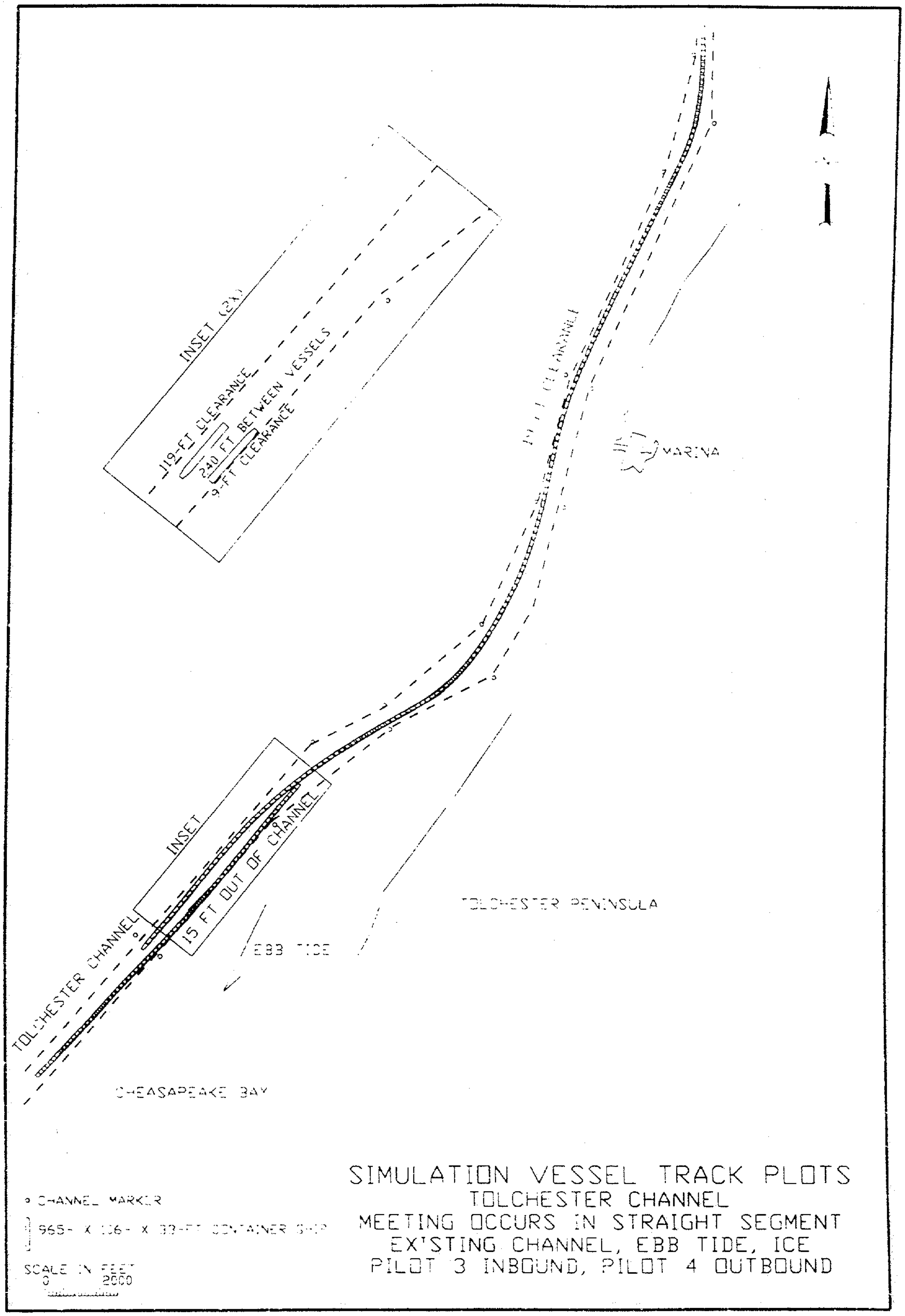
PRELIMINARY



- - - - - - - OUTBOUND SHIP
- - - - - - - INBOUND SHIP

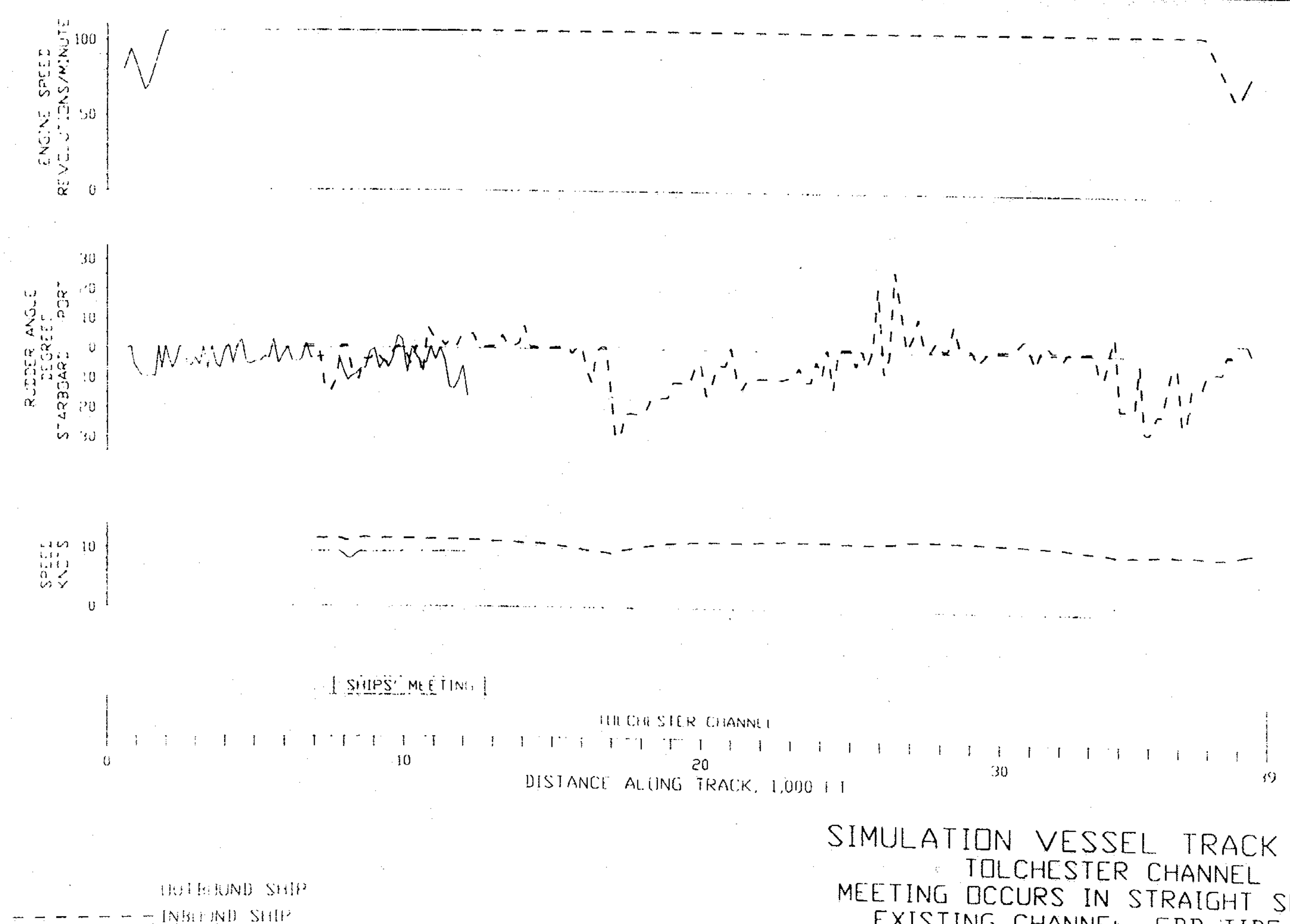
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

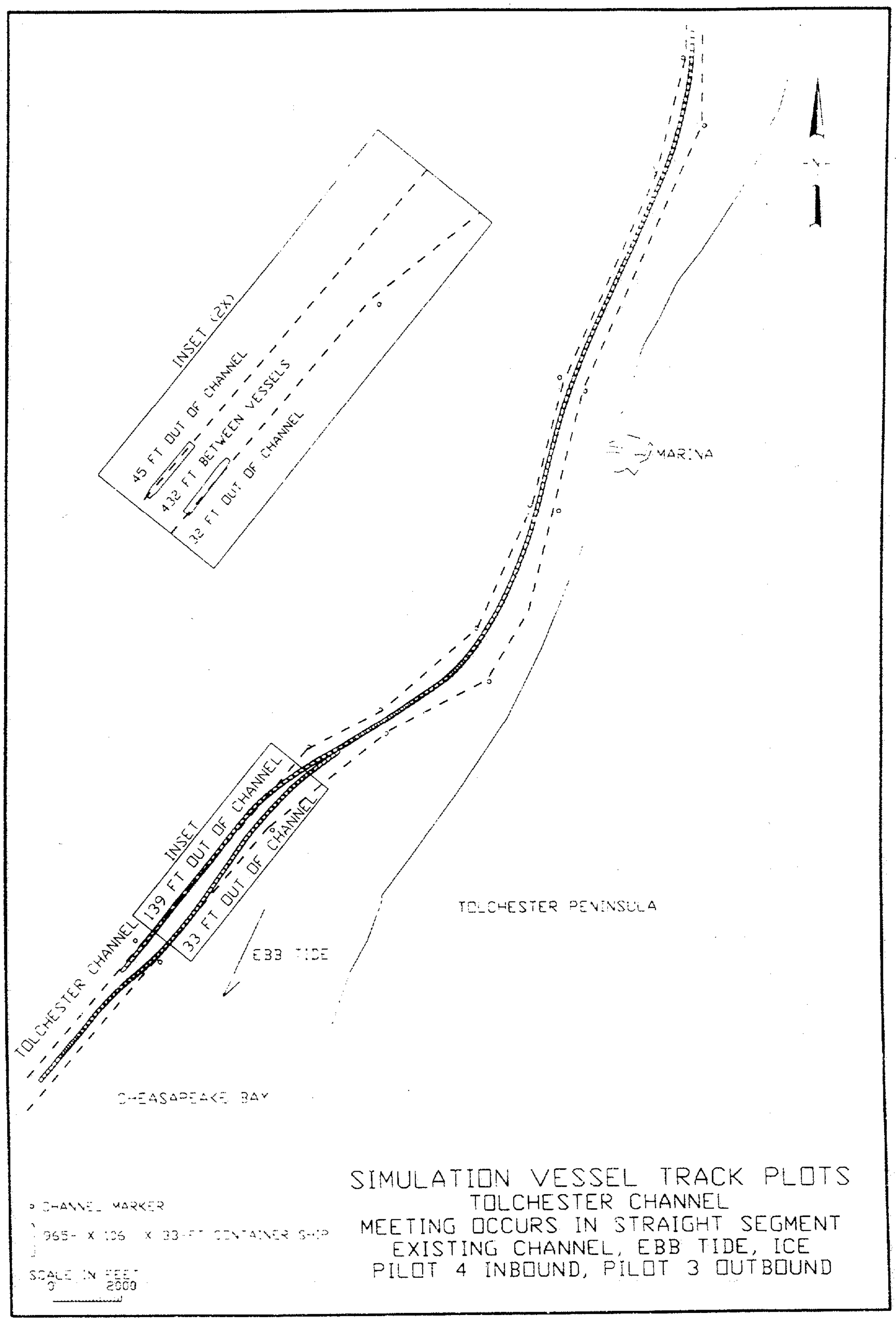
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

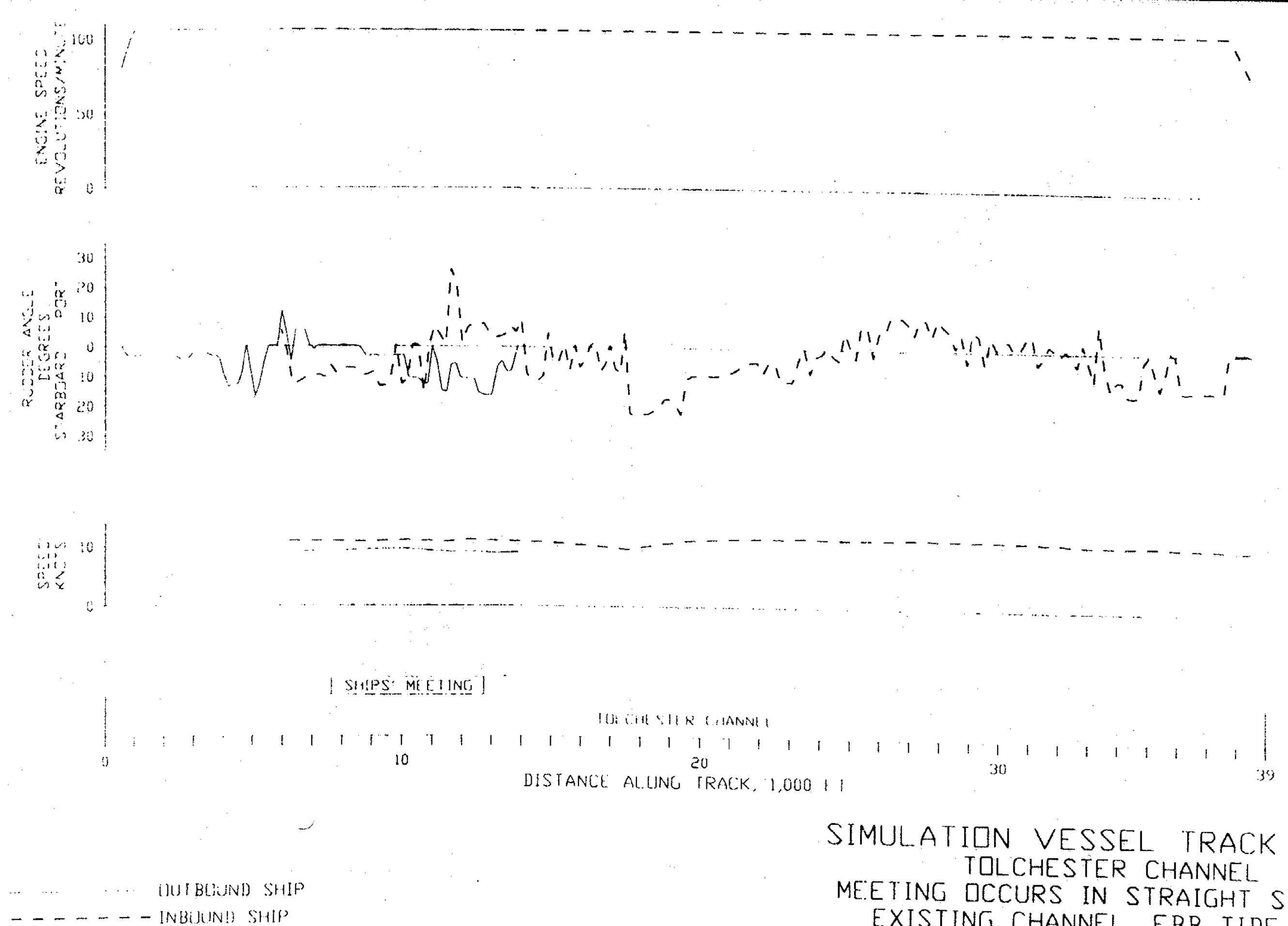
Plate 120

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

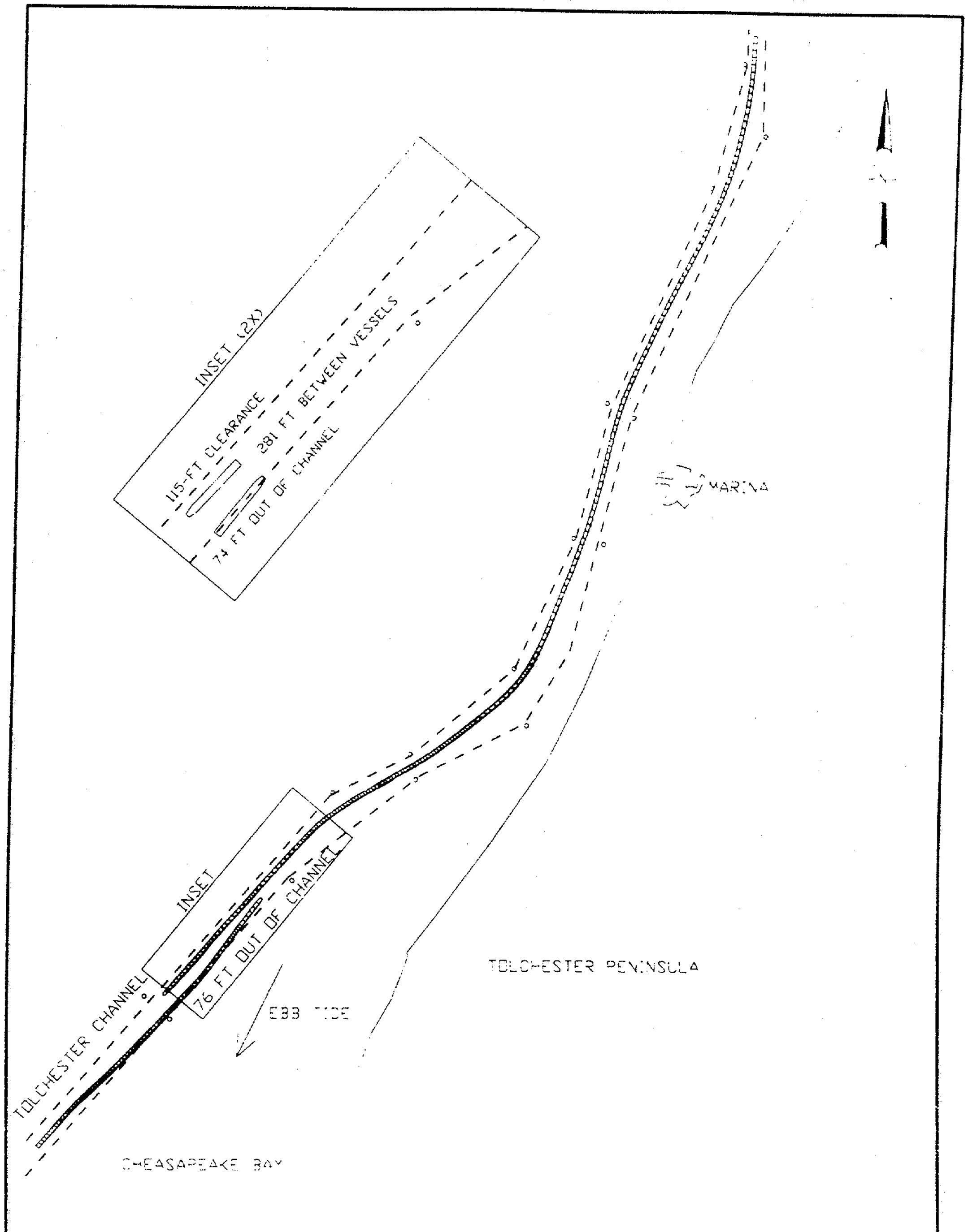
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

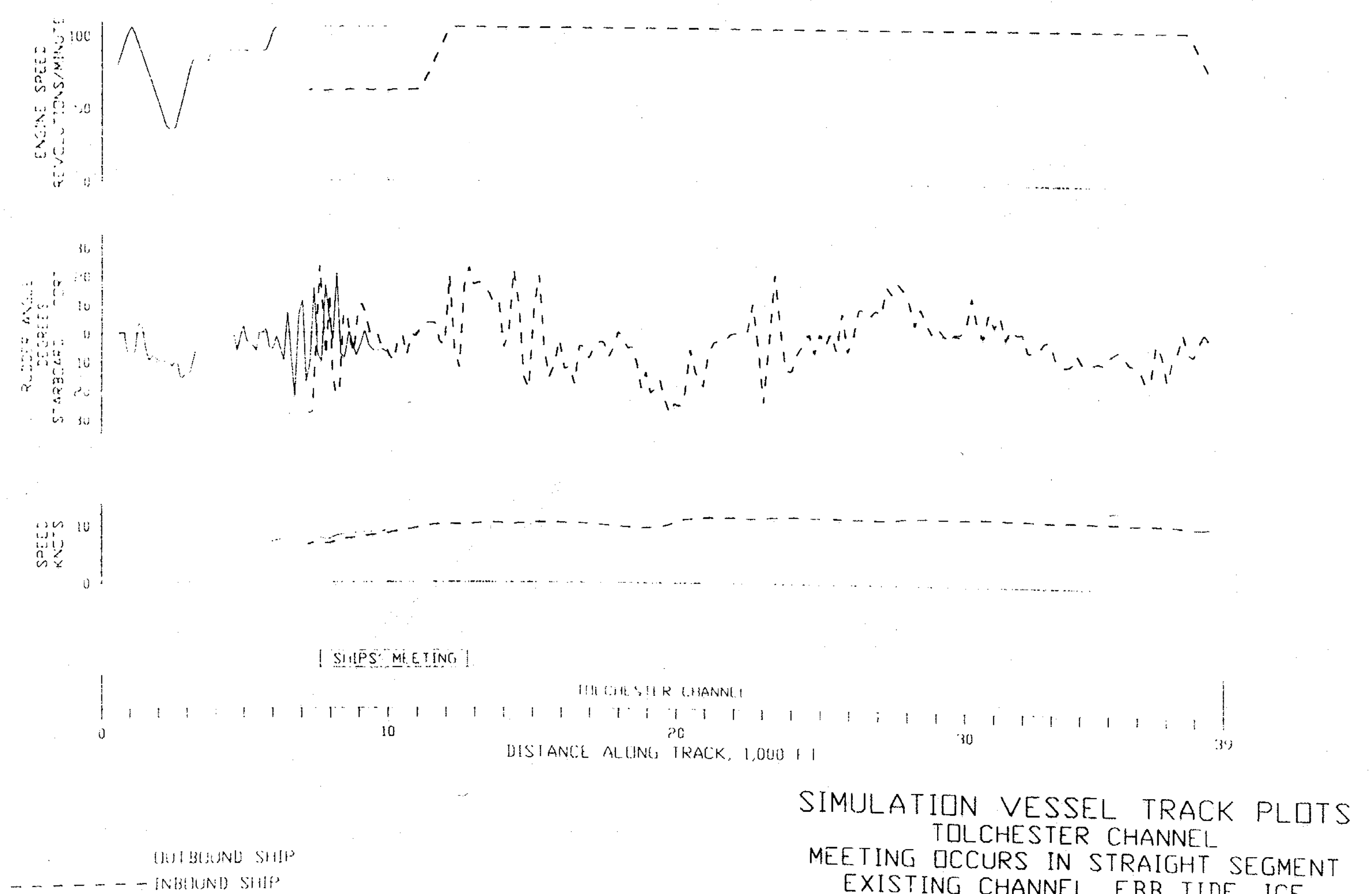
Plate 122

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

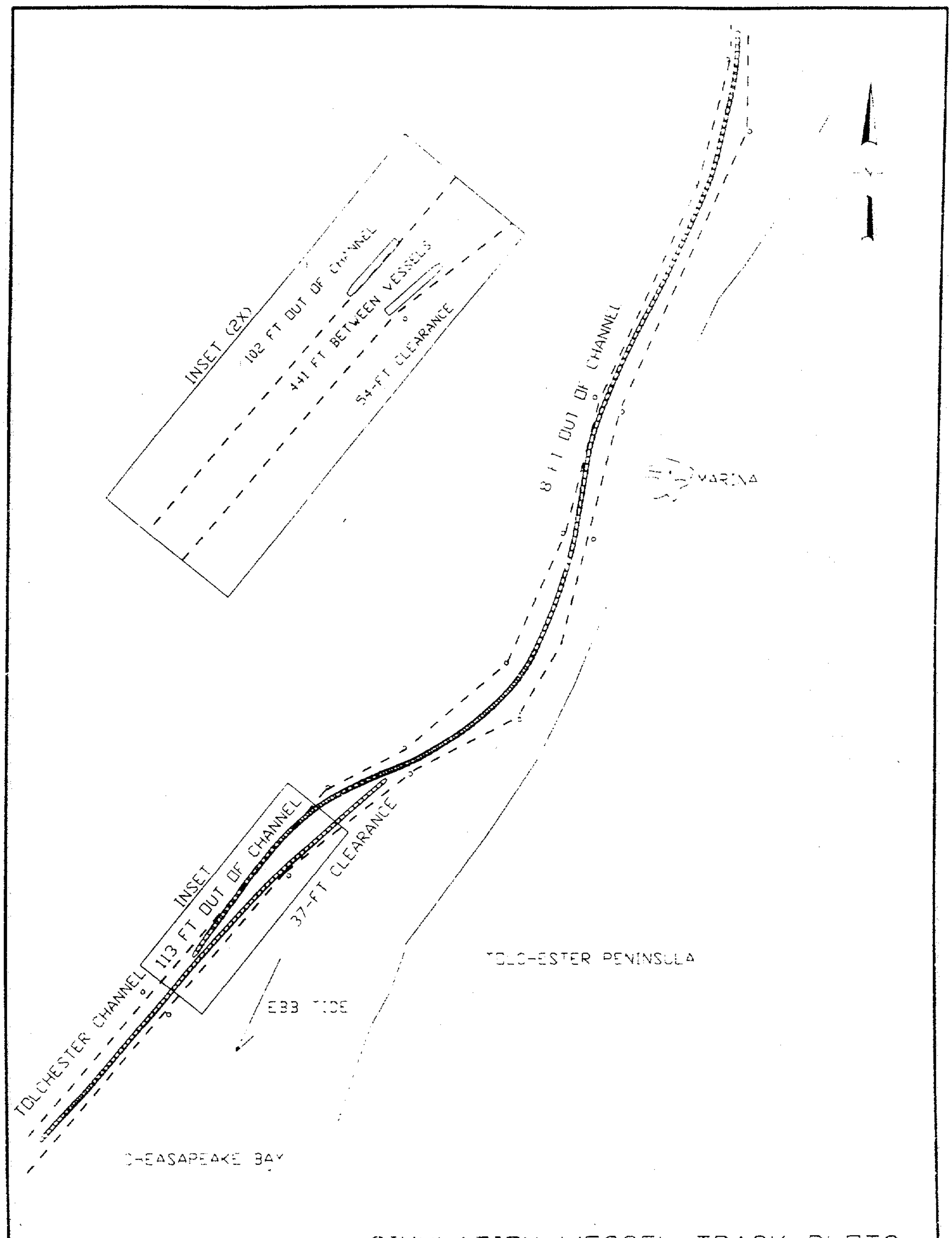
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

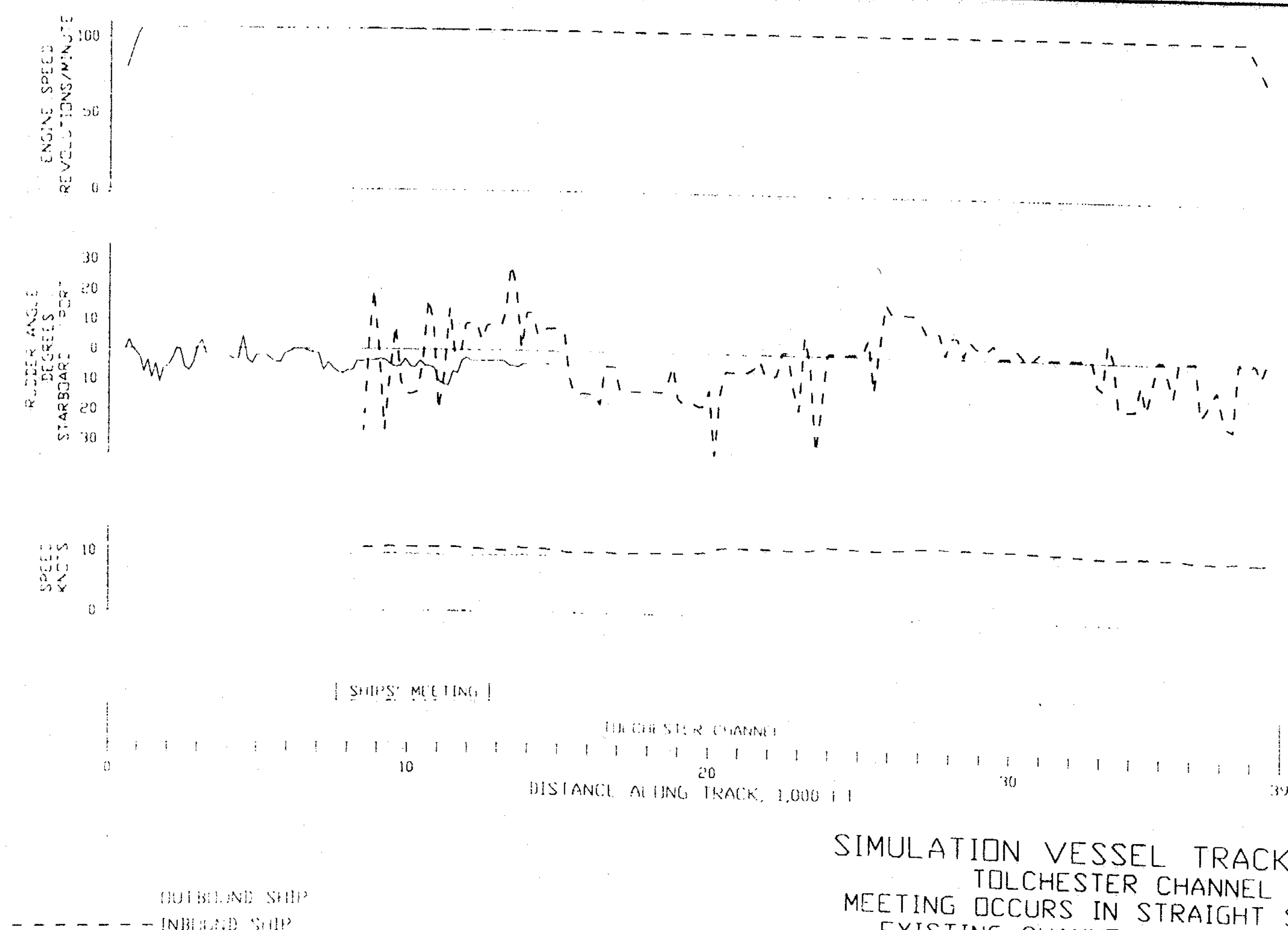
Plate 124

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

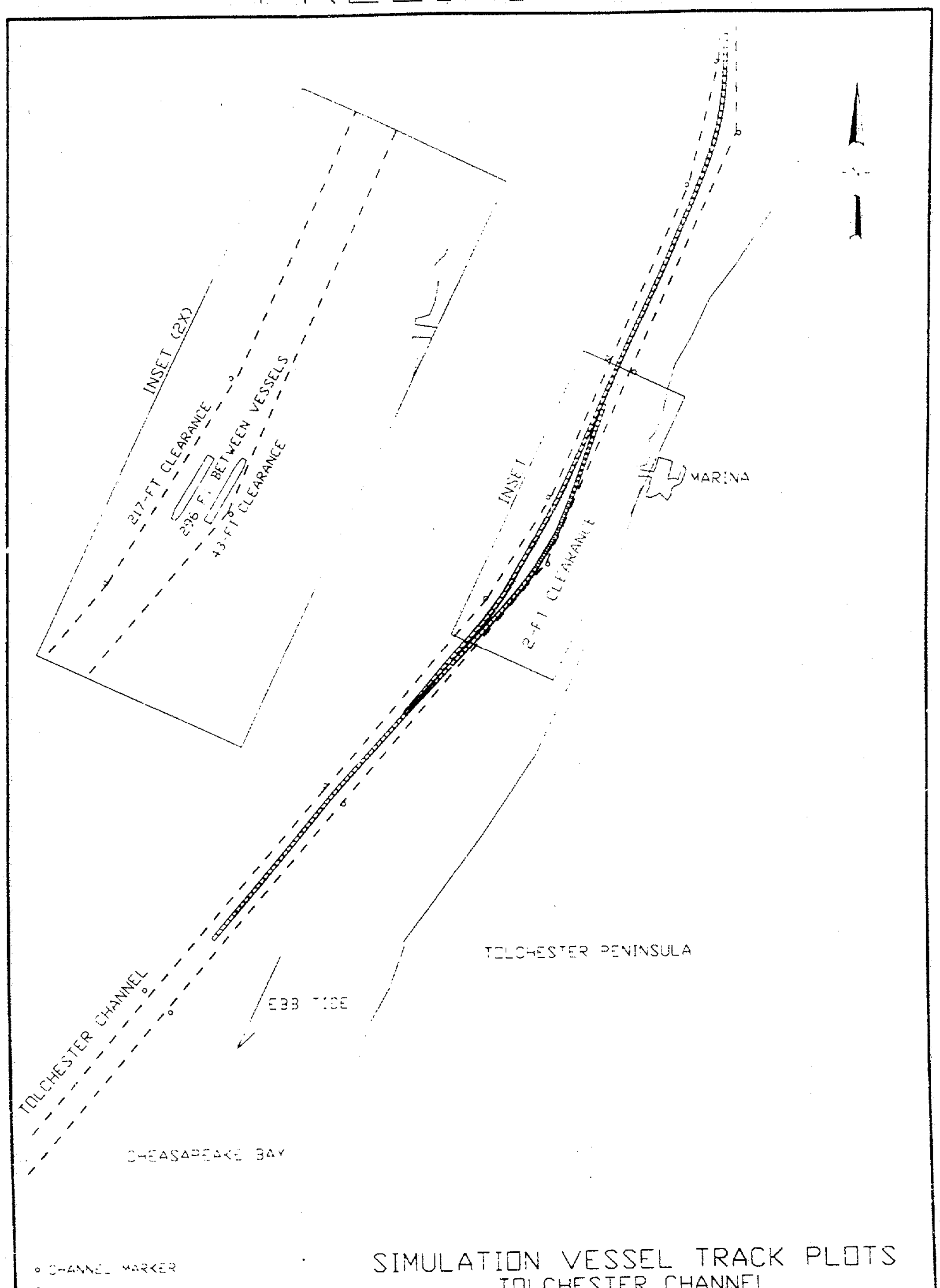
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, EBB TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 126

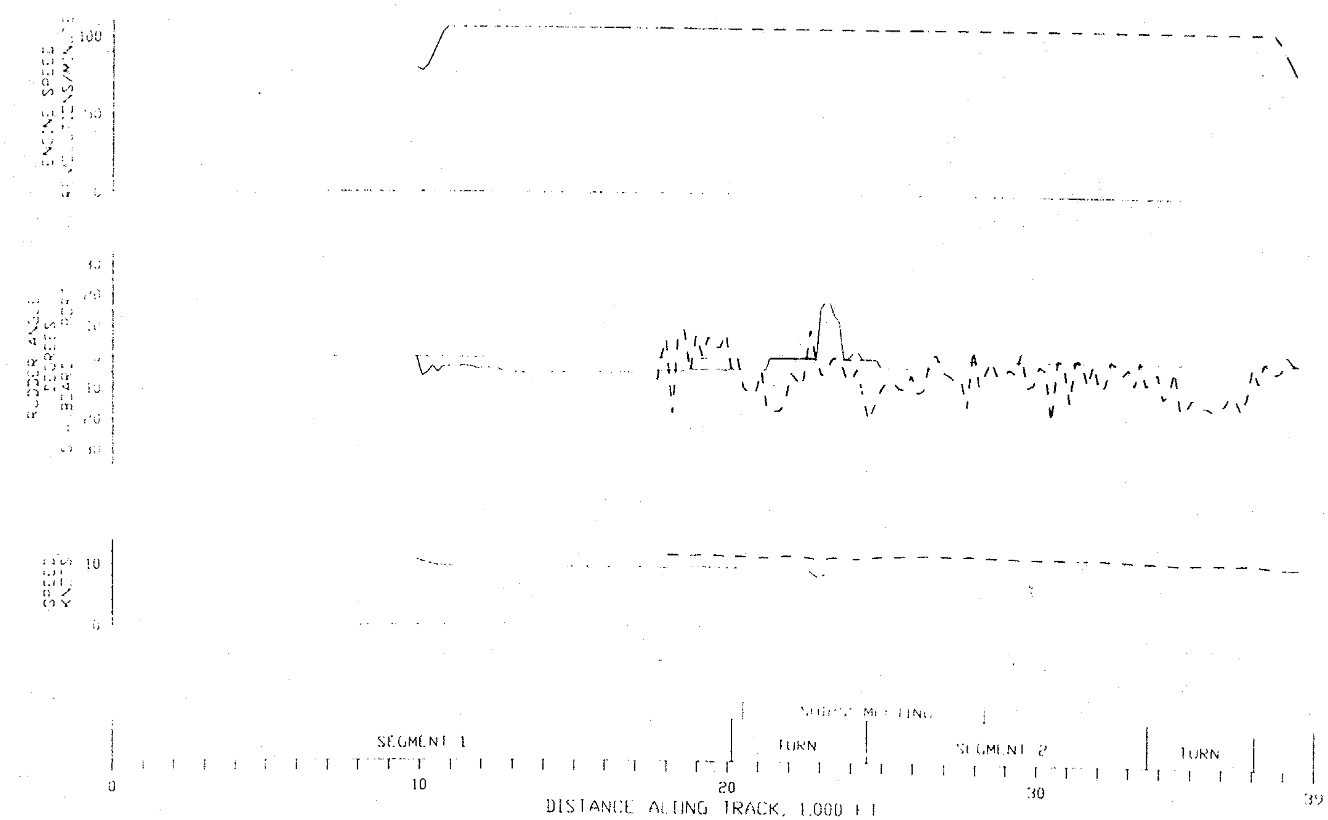
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 127

PRELIMINARY

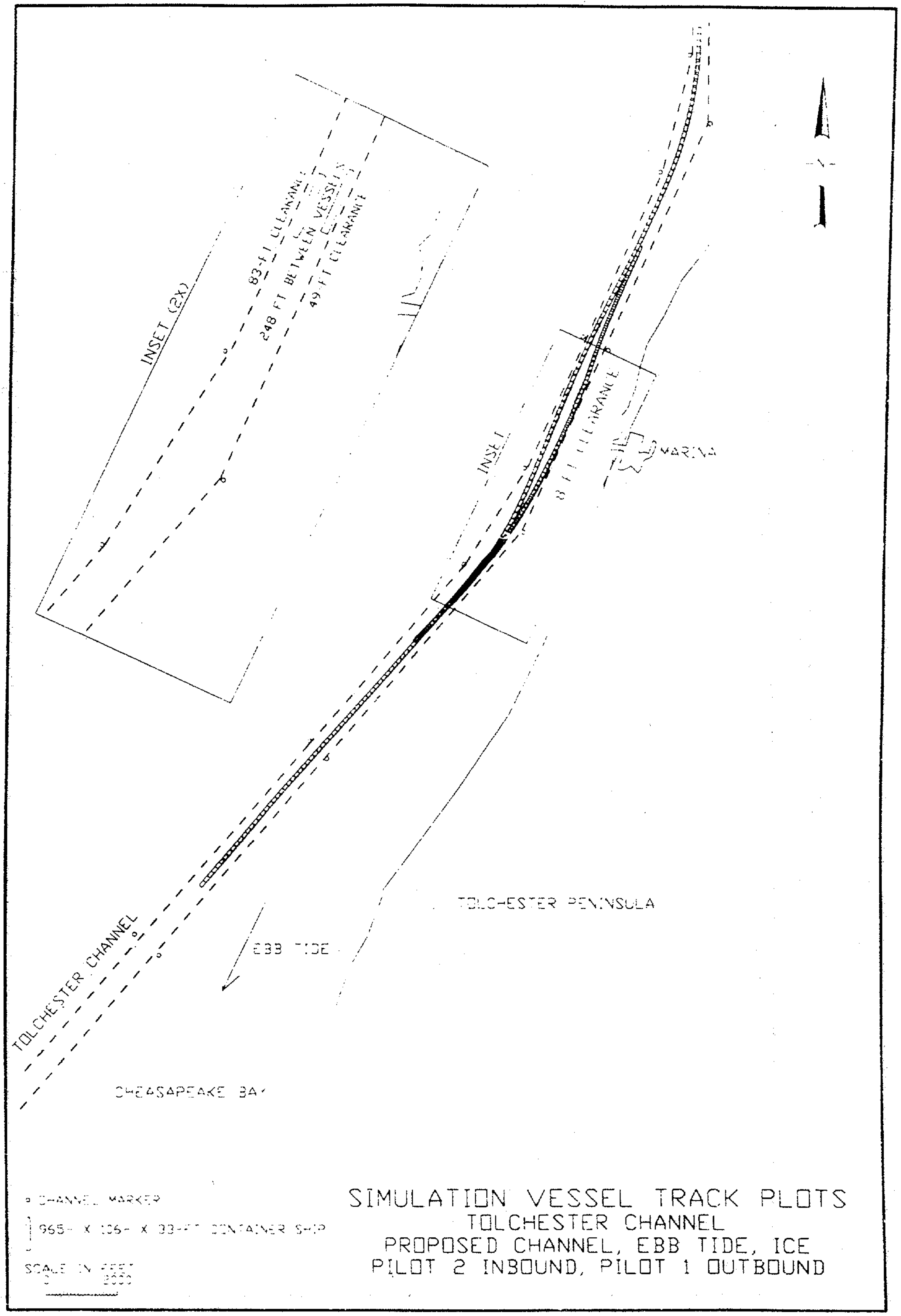


OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

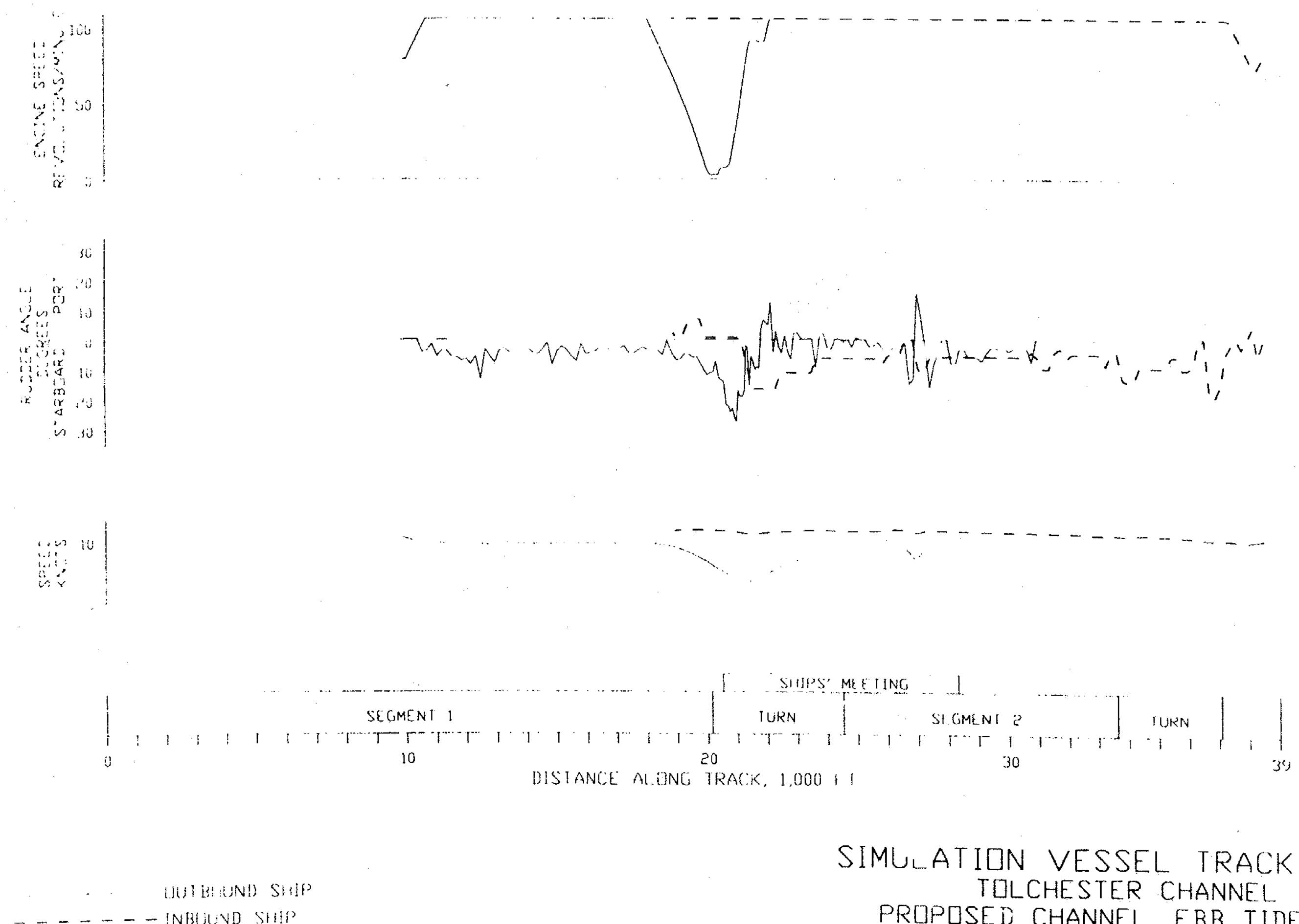
Plate 128

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

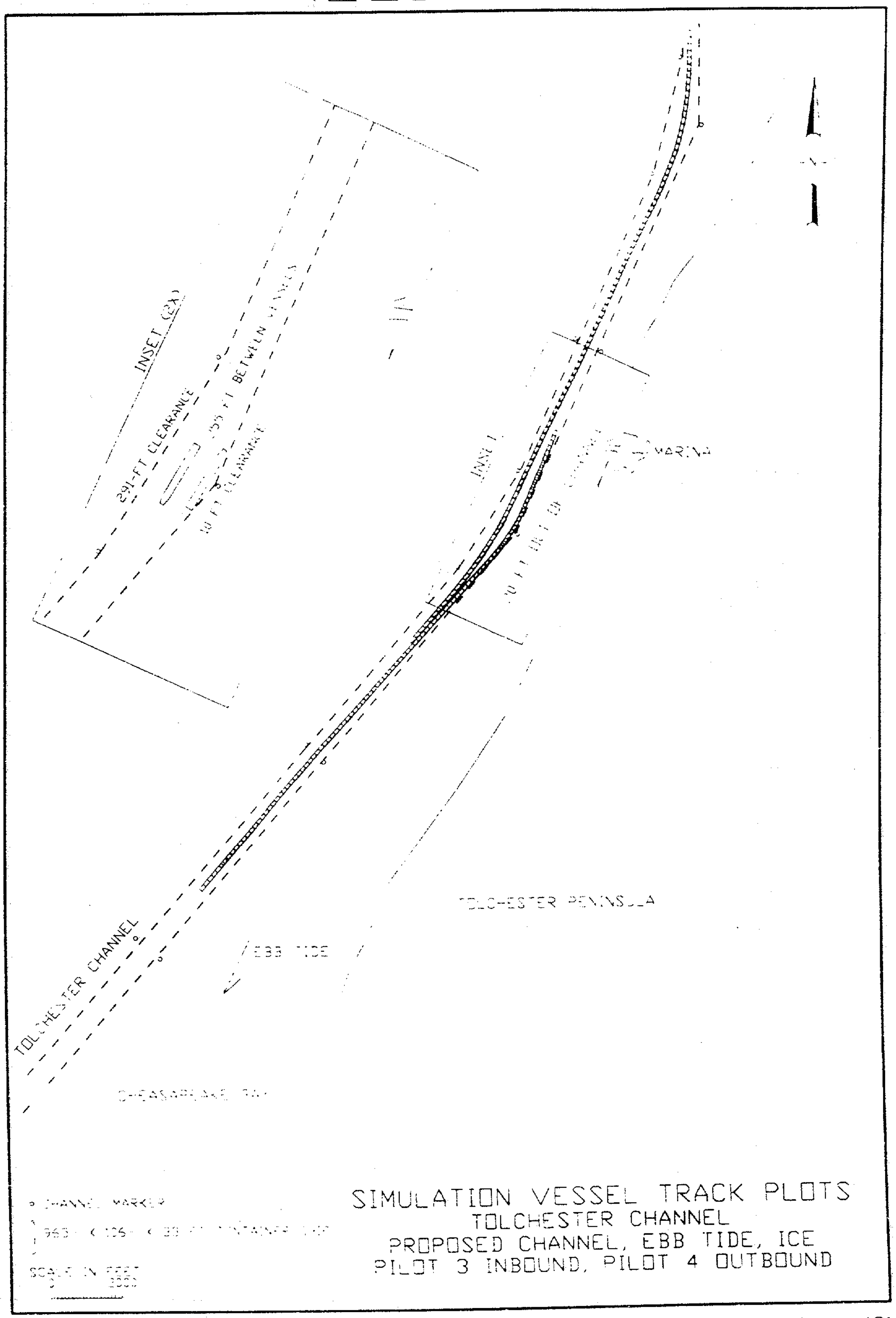
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 130

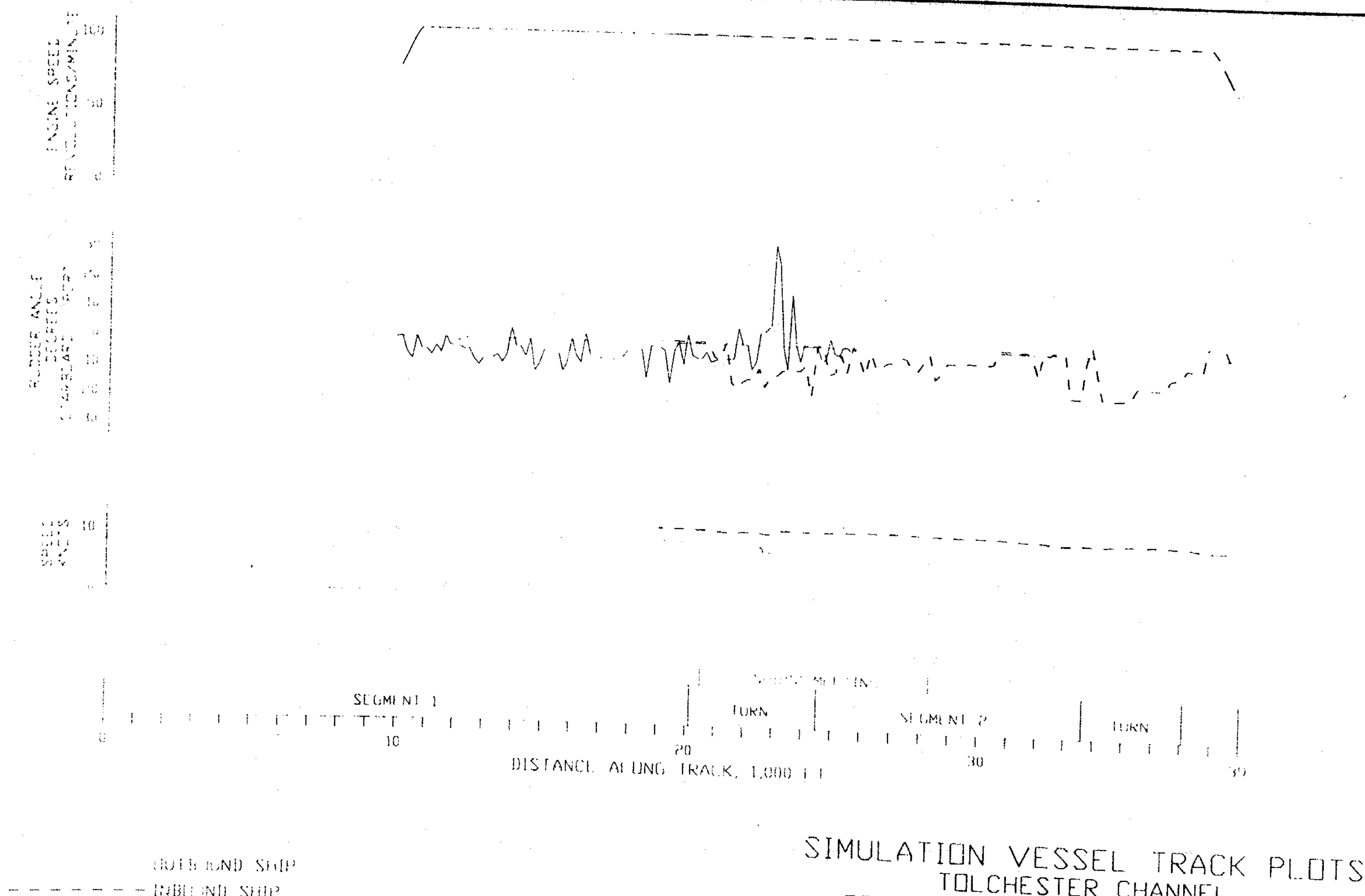
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 131

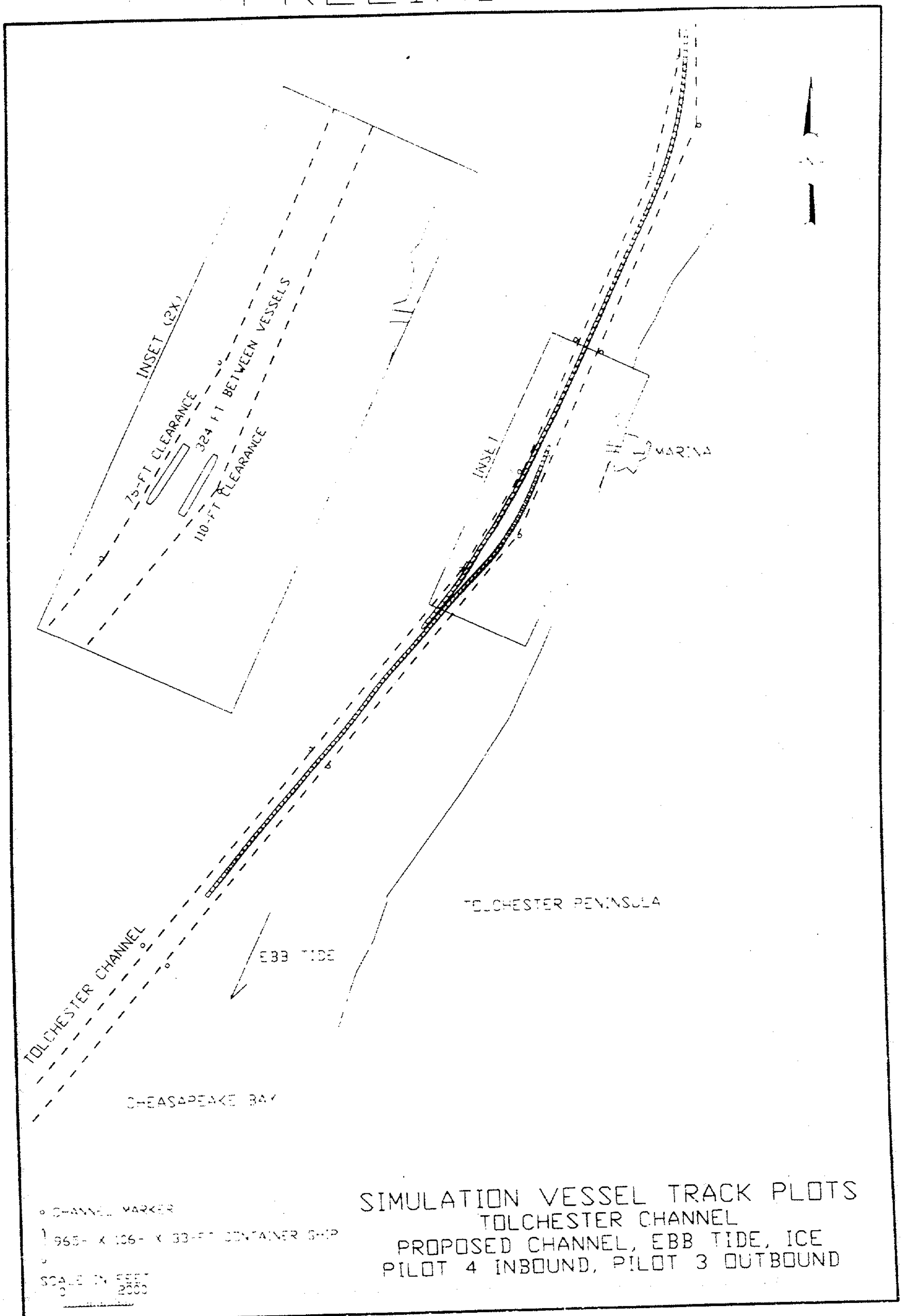
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 132

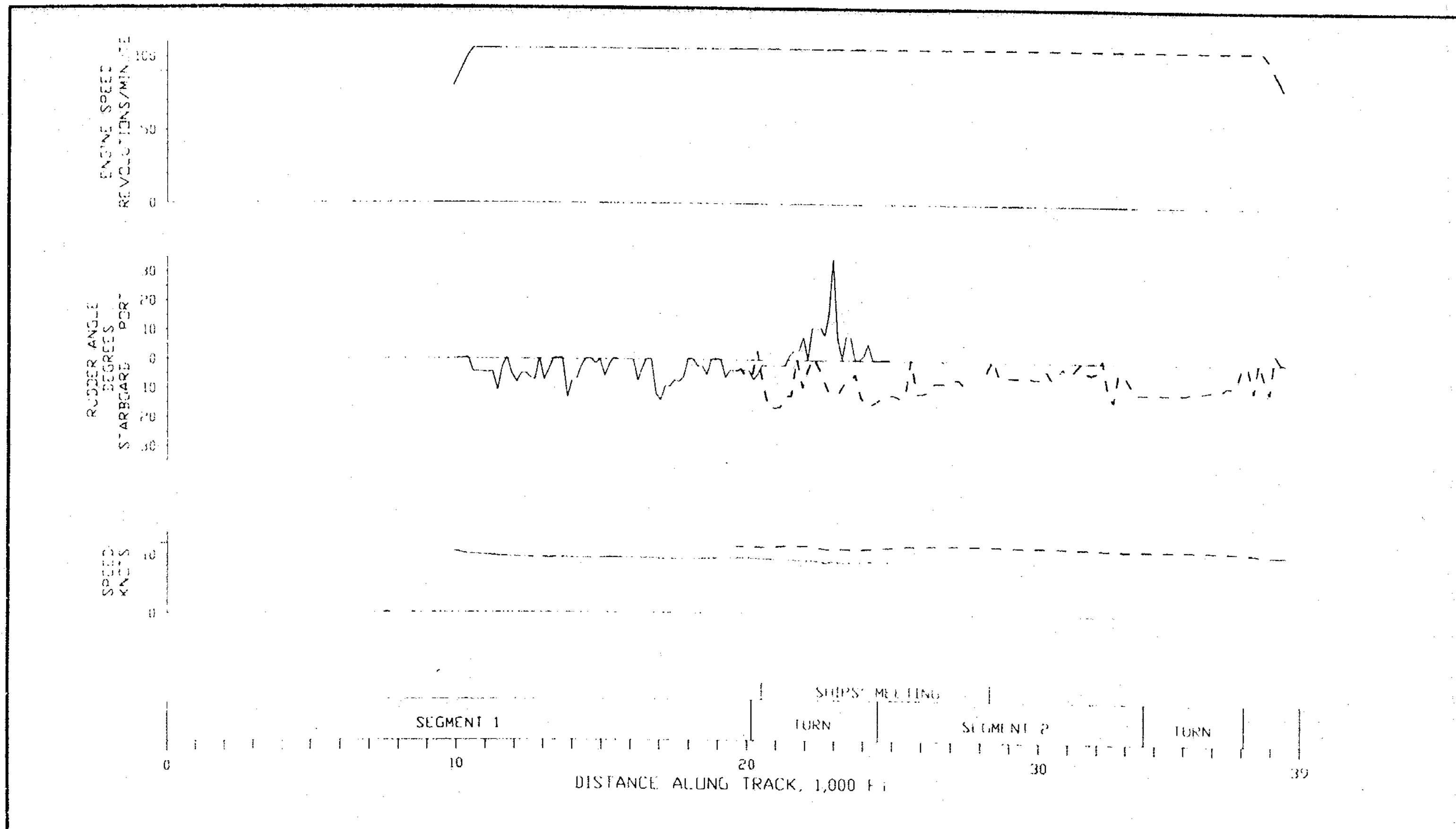
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 133

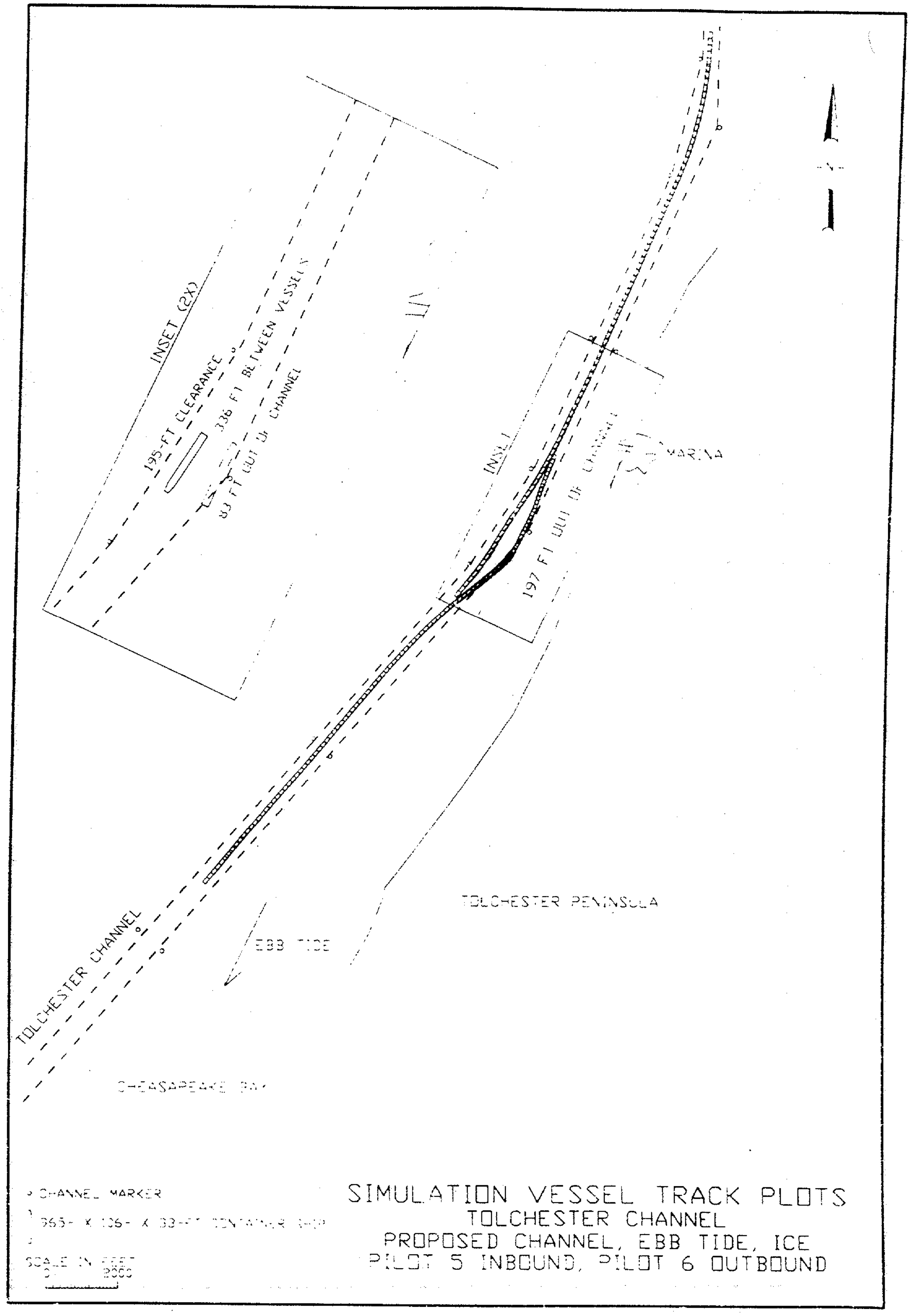
PRELIMINARY



SIMU' ATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

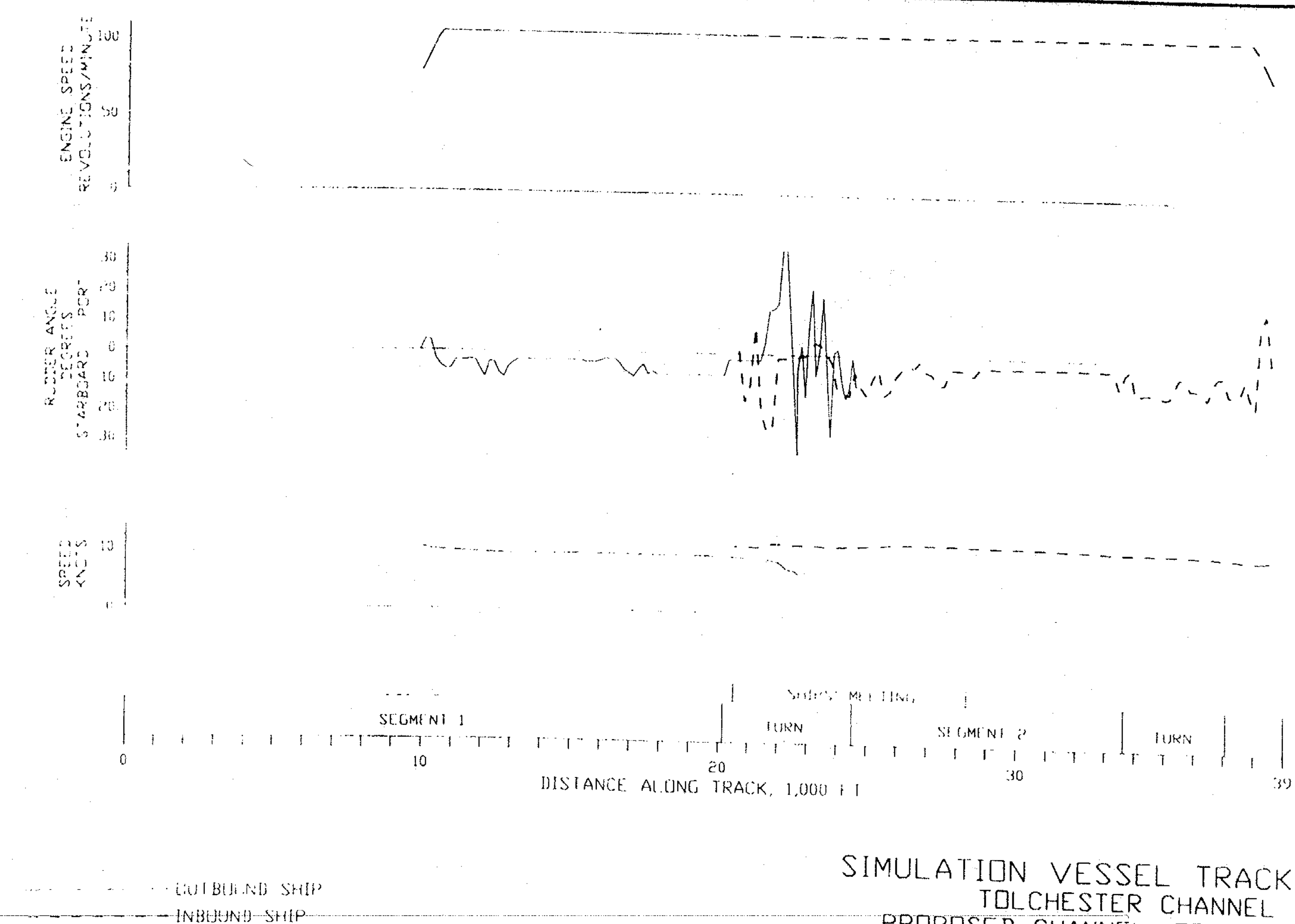
Plate 134

PRELIMINARY



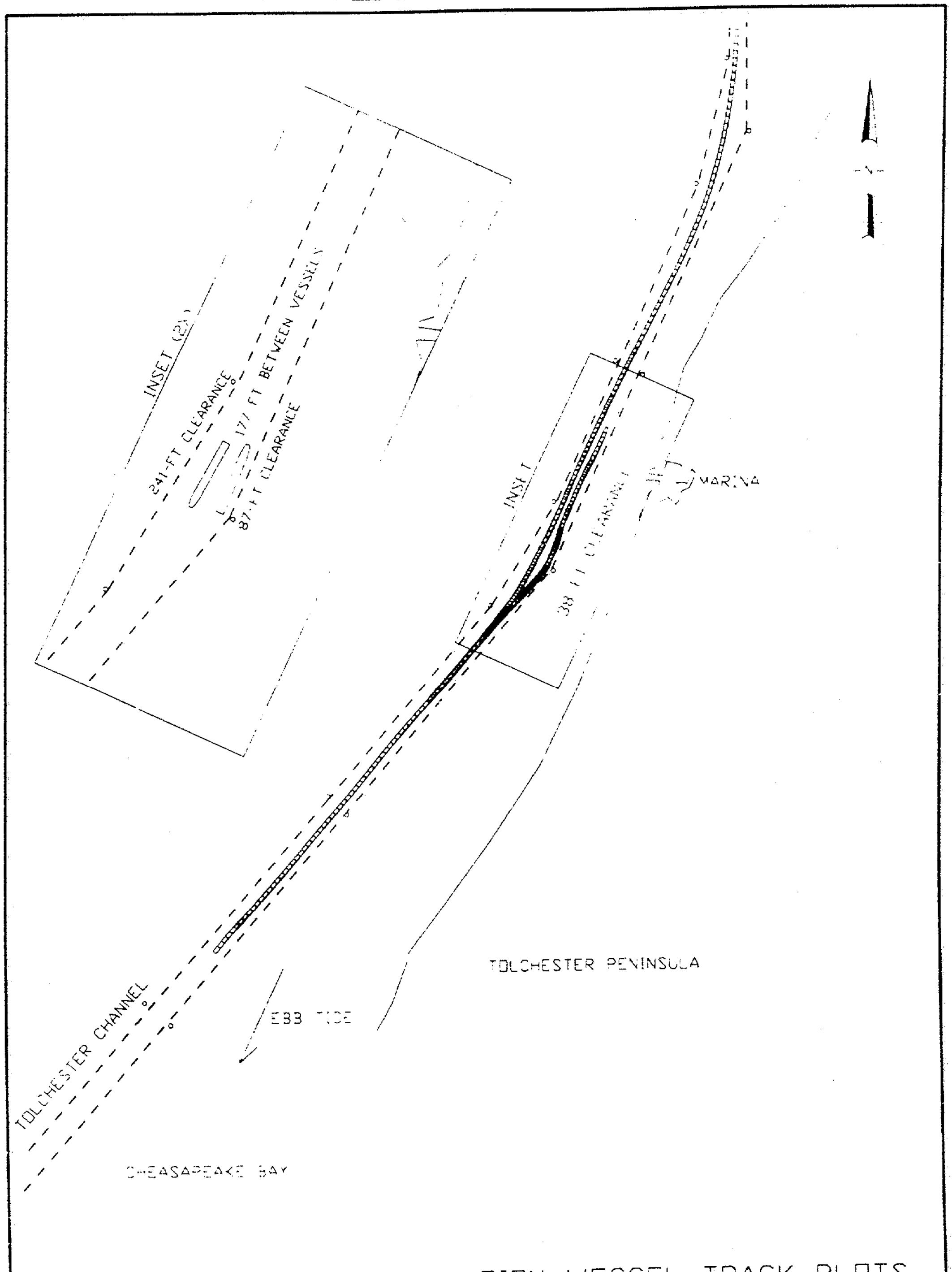
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

PRELIMINARY



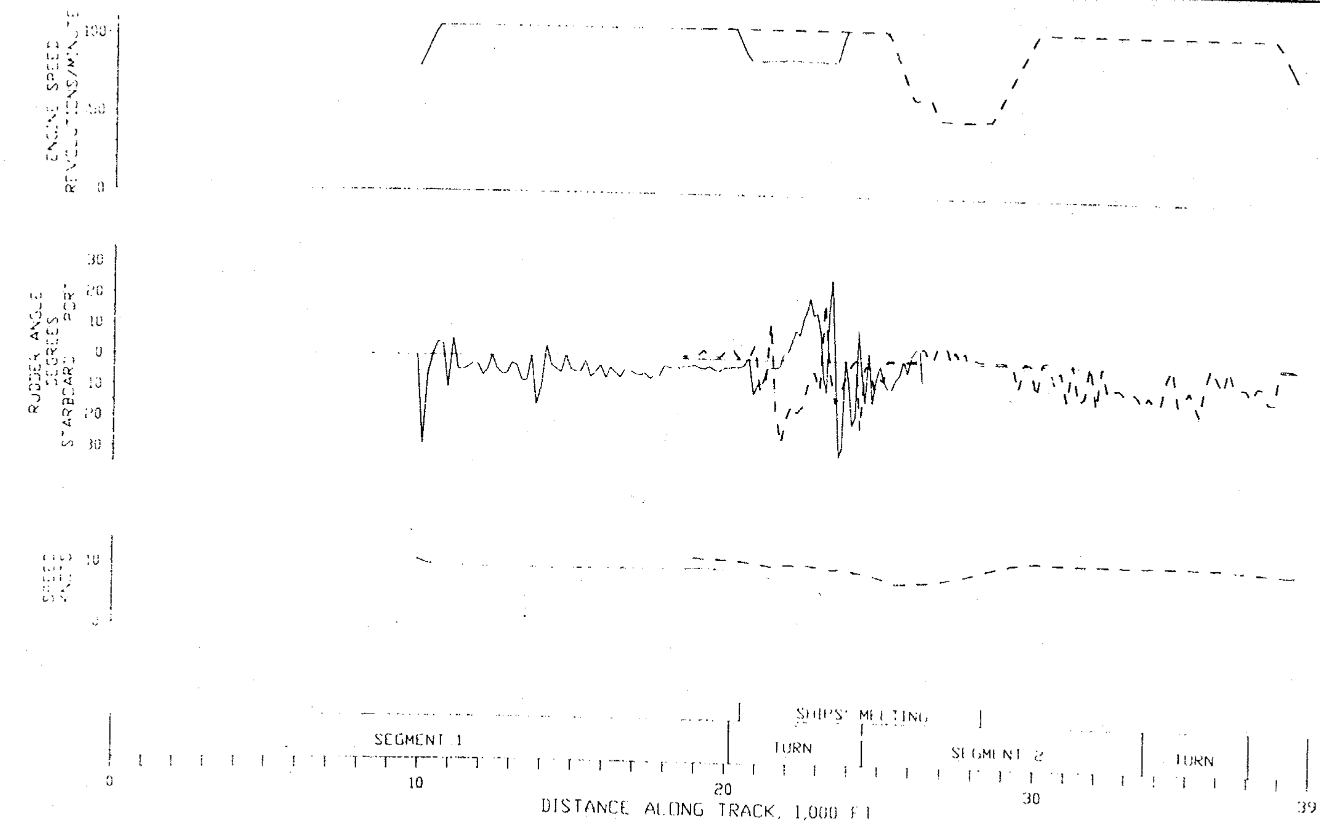
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

PRELIMINARY

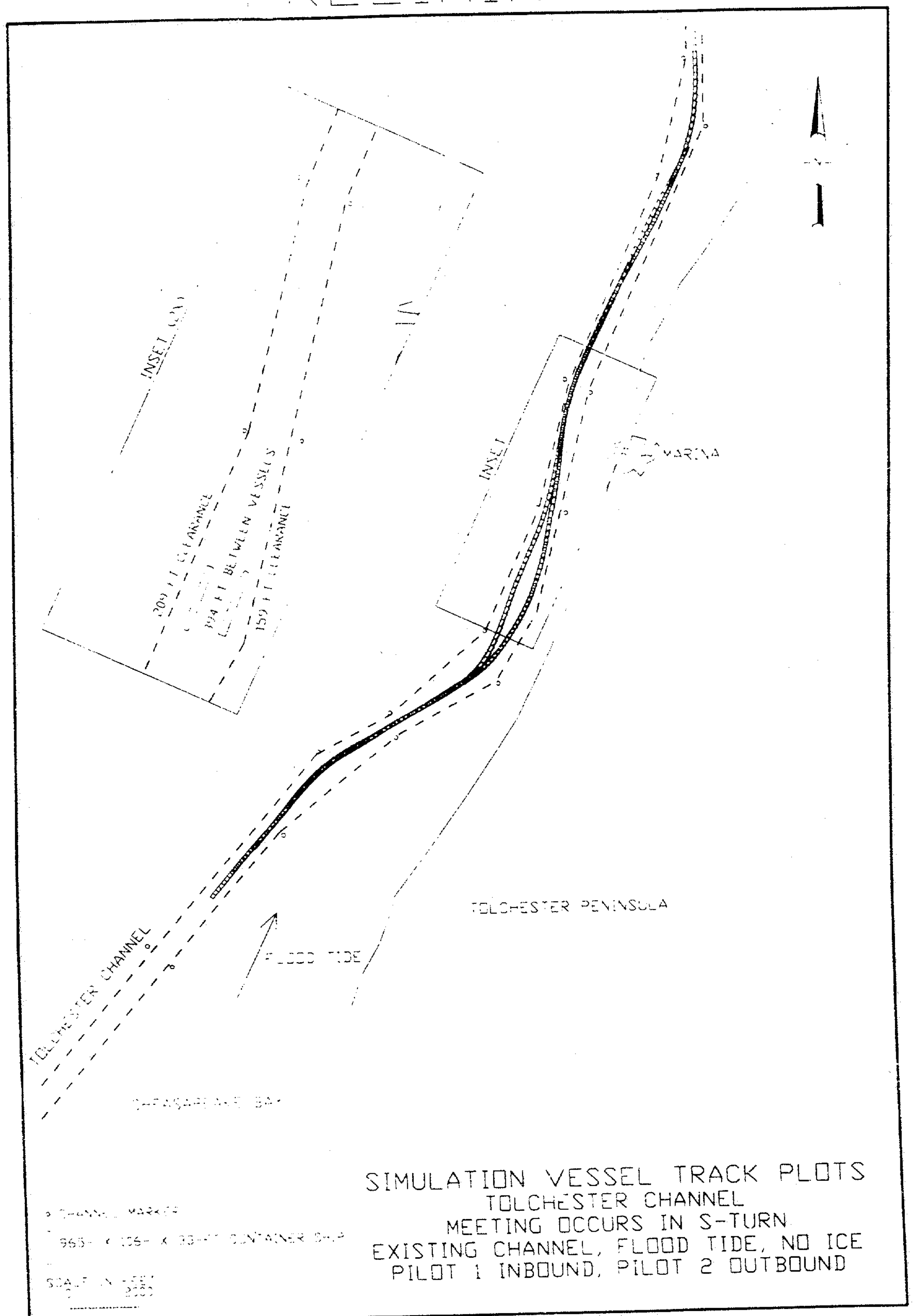


· · · · · · · OUTBOUND SHIP
– – – – – – – INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, EBB TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

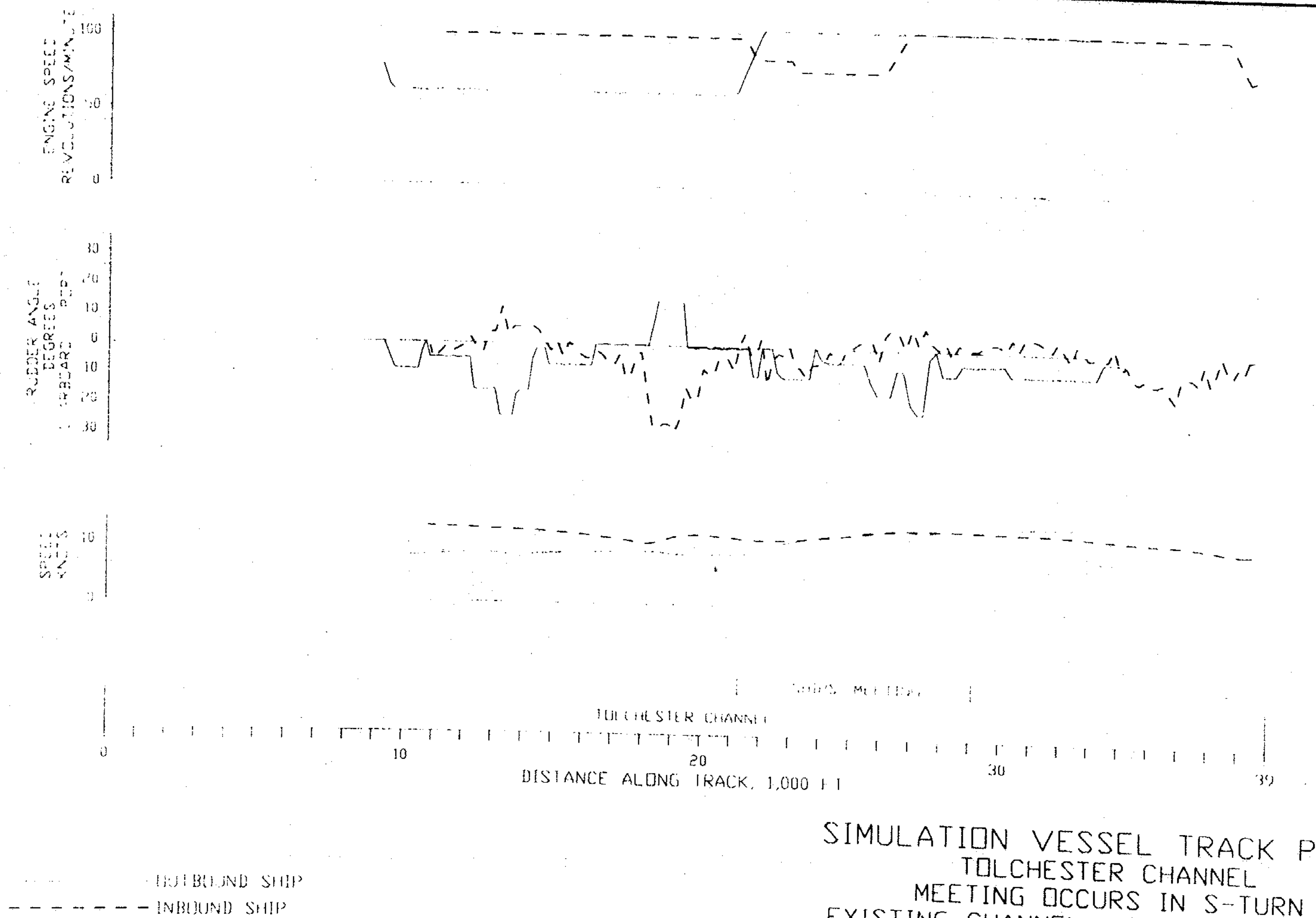
Plate 138

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

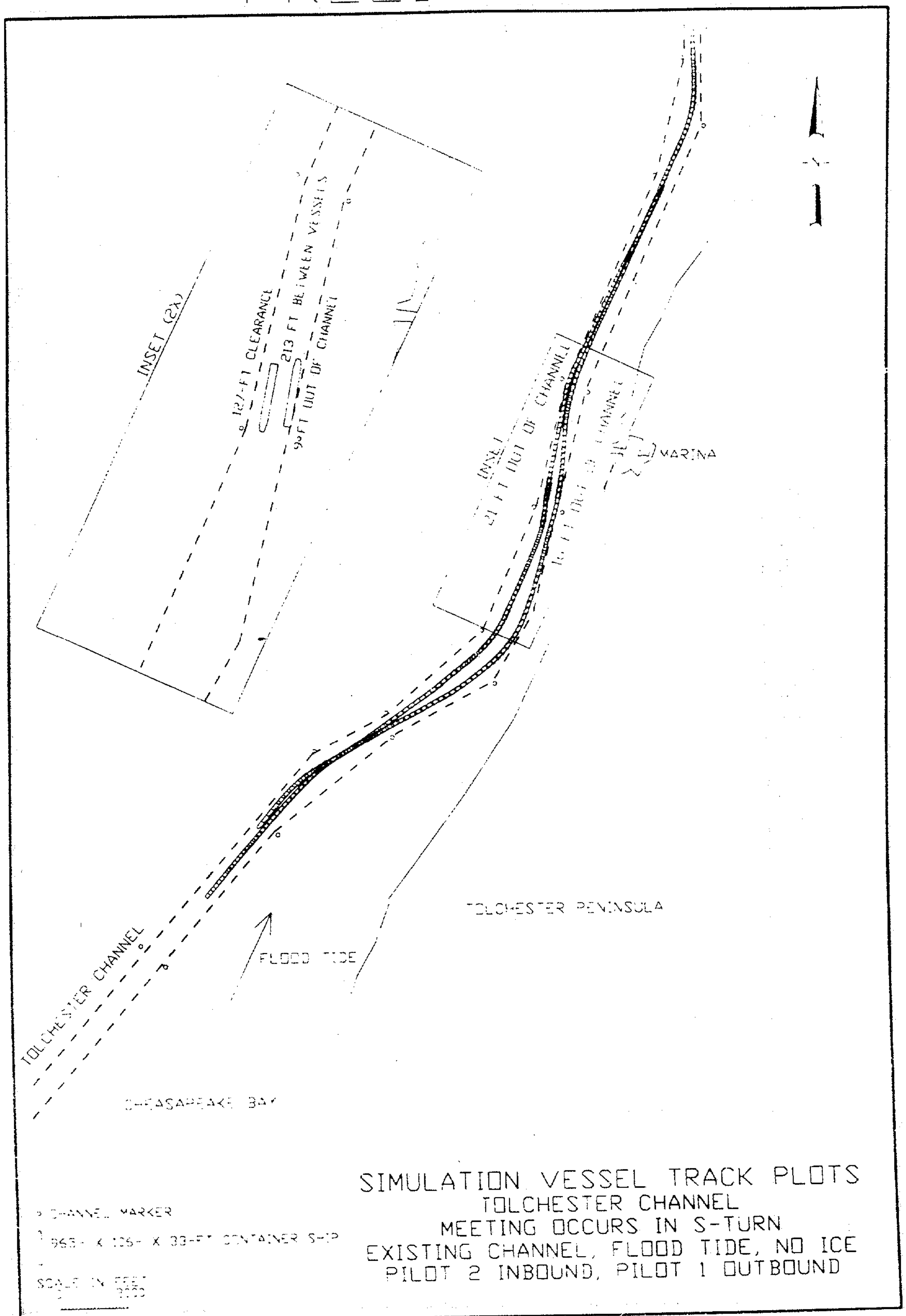
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 140

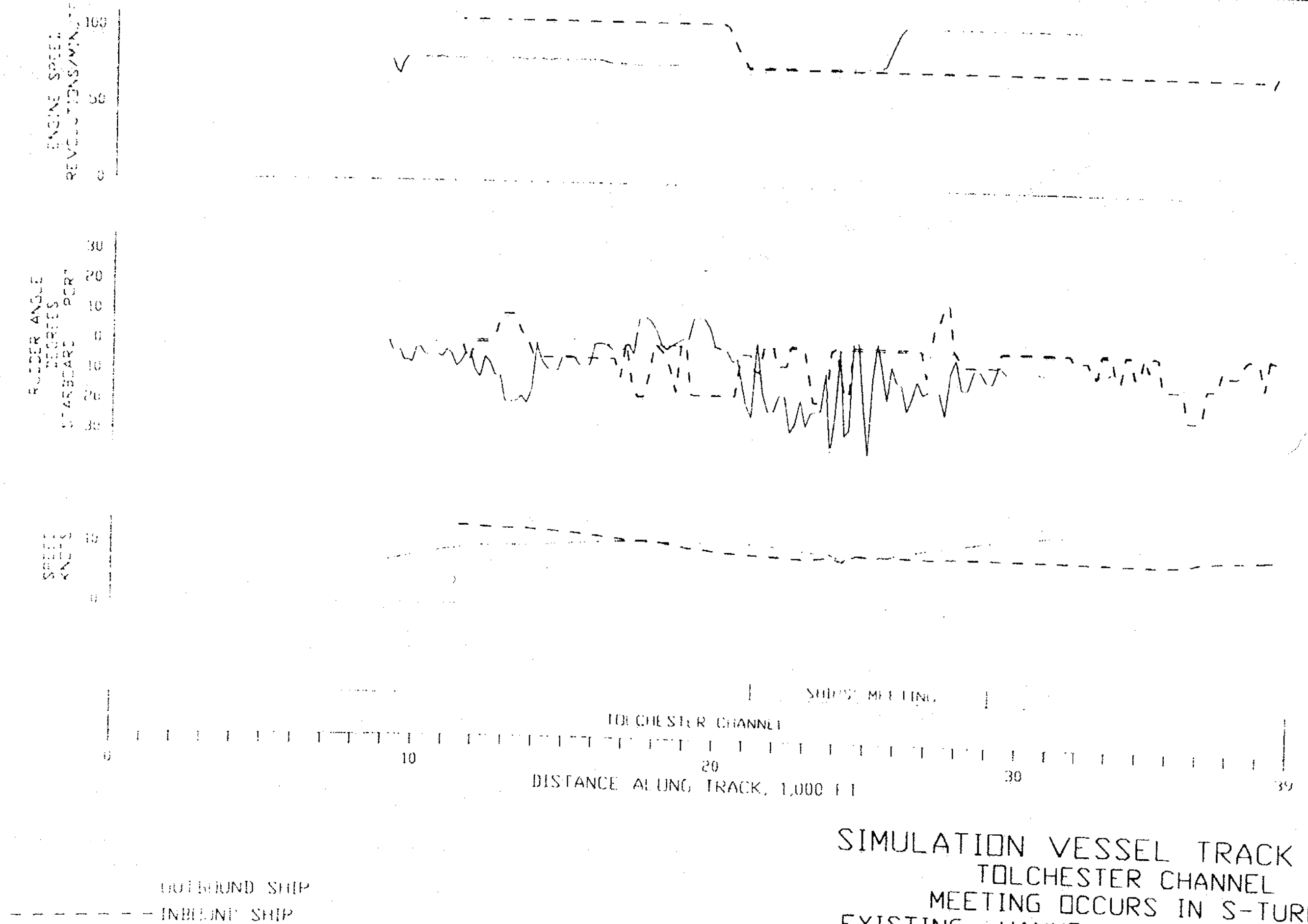
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 141

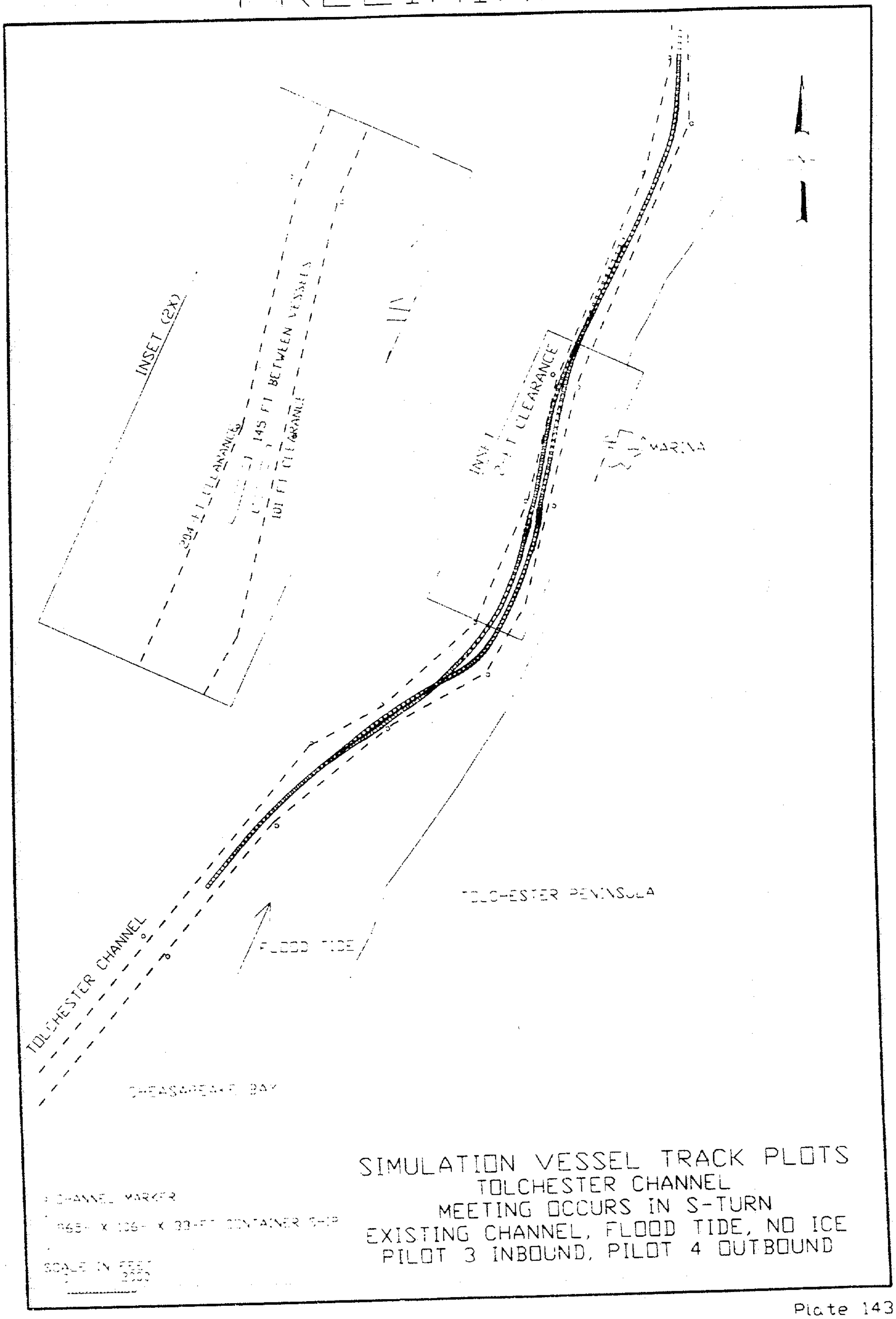
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 142

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY

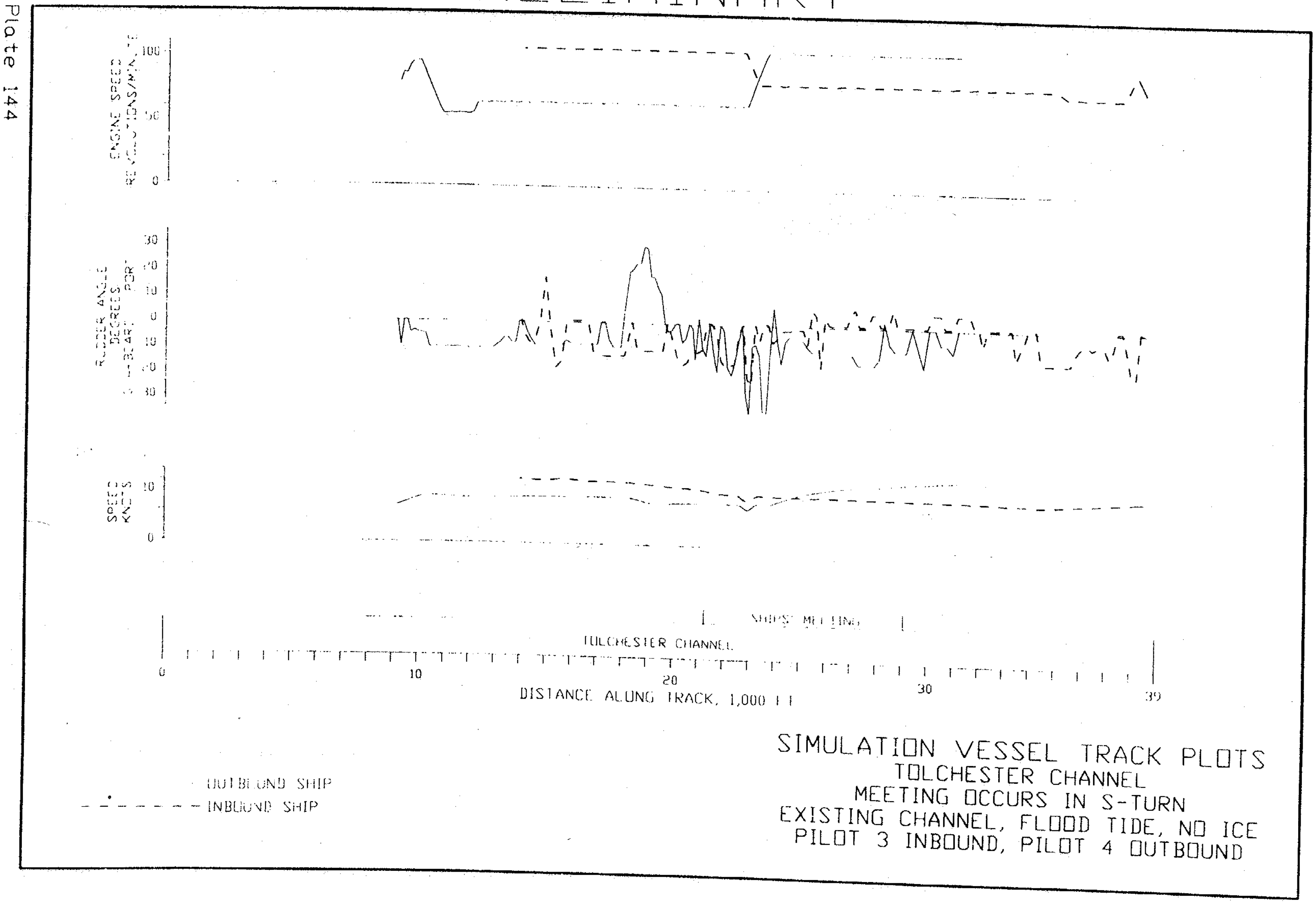
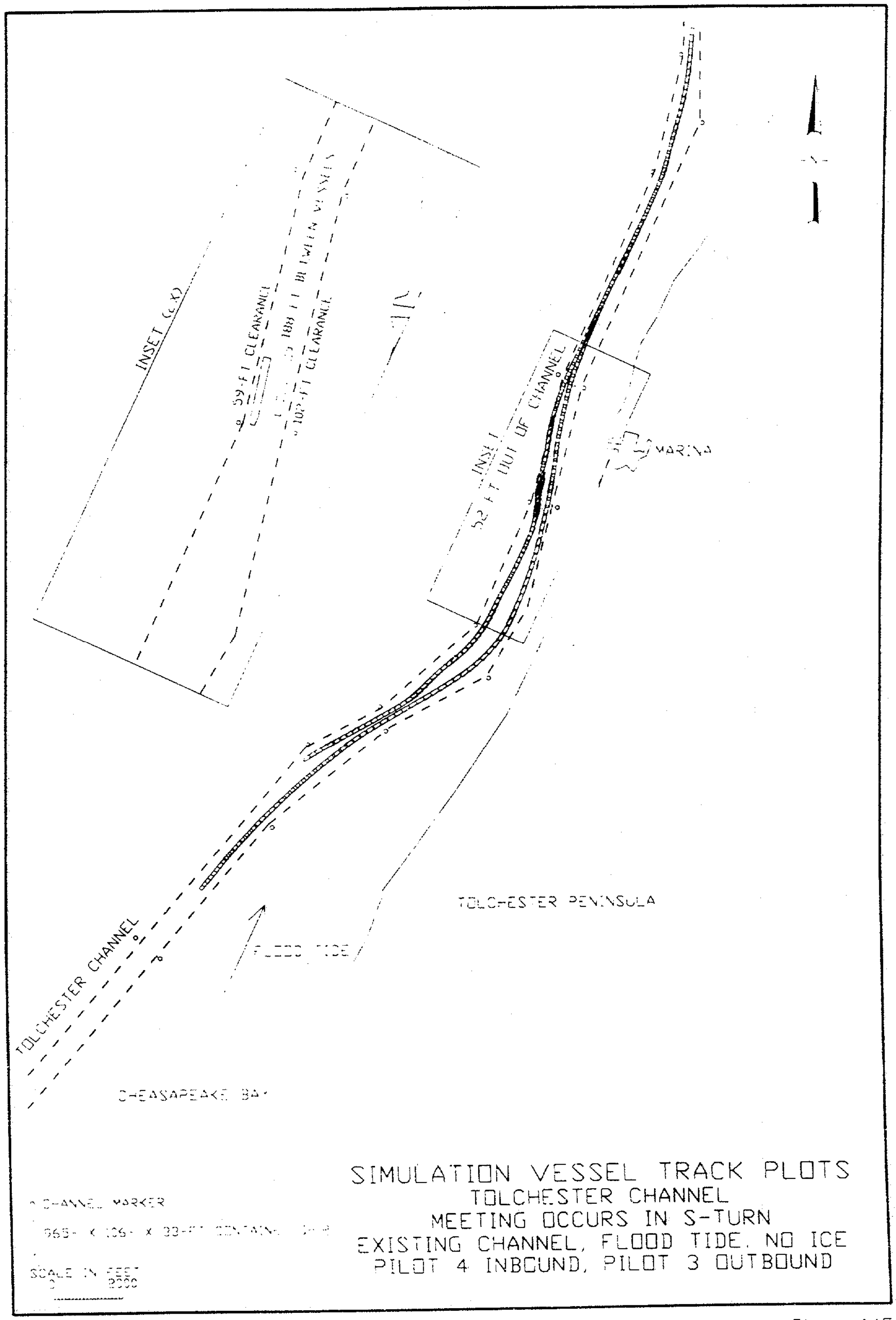


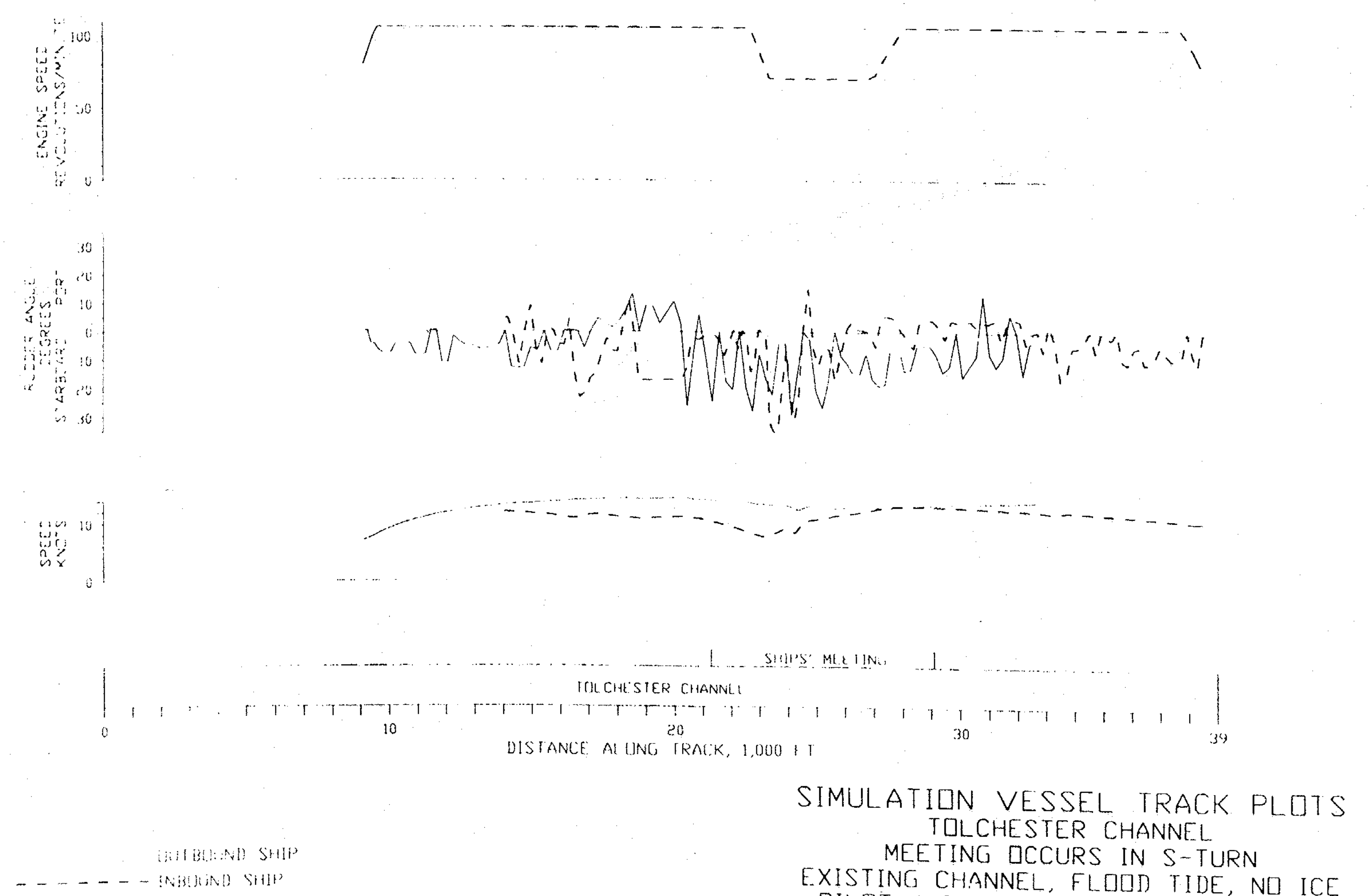
Plate 144

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

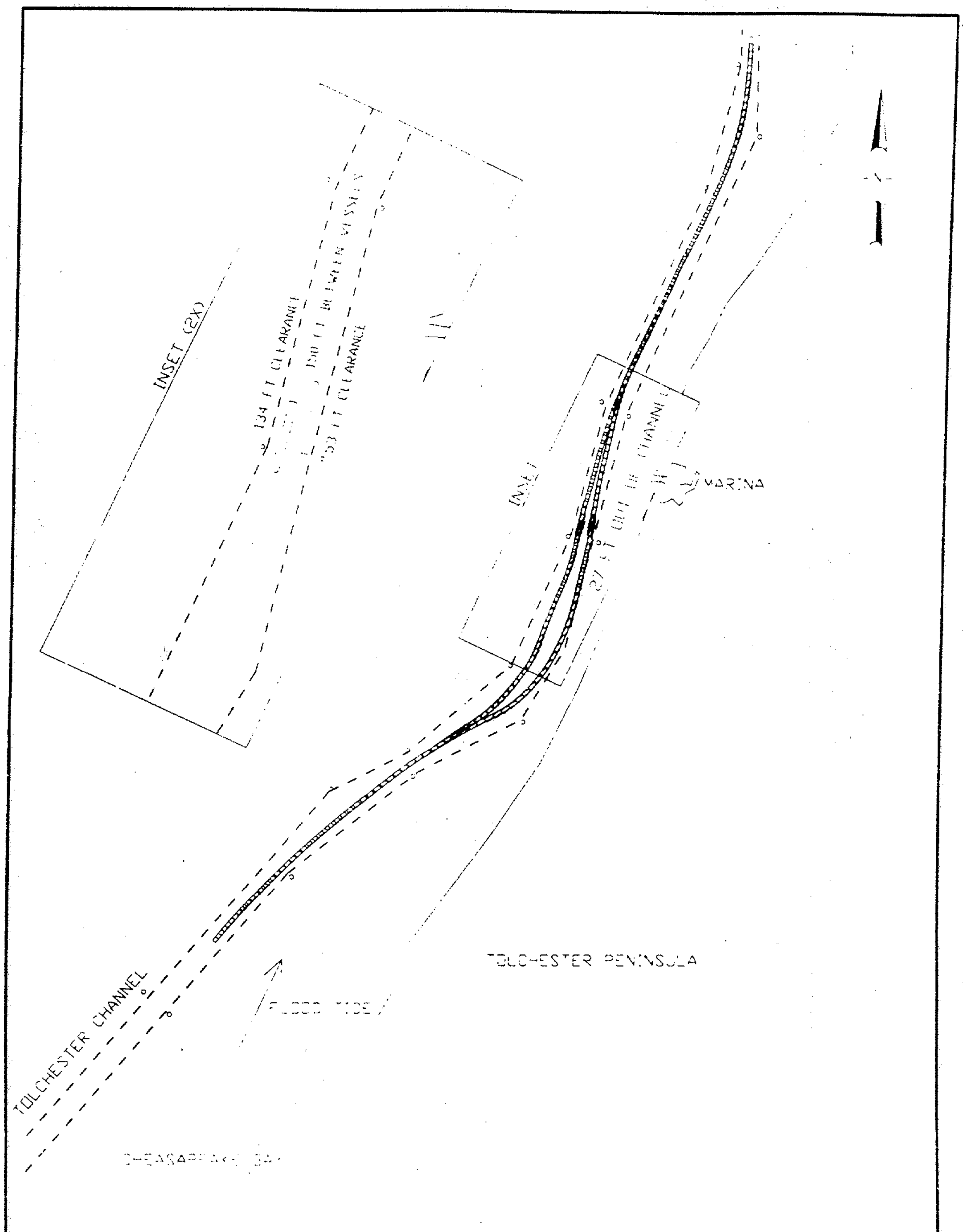
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

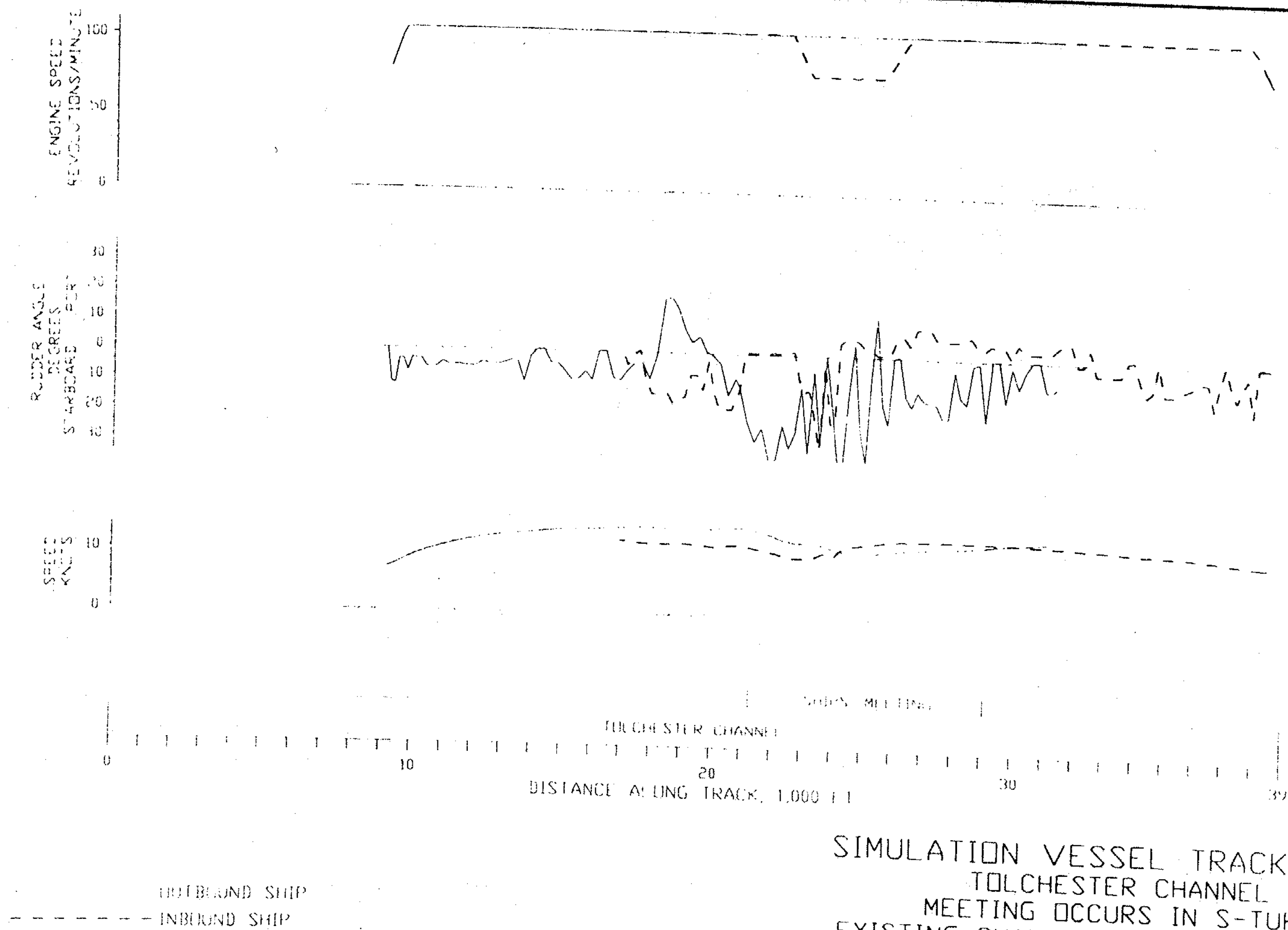
Plate 146

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

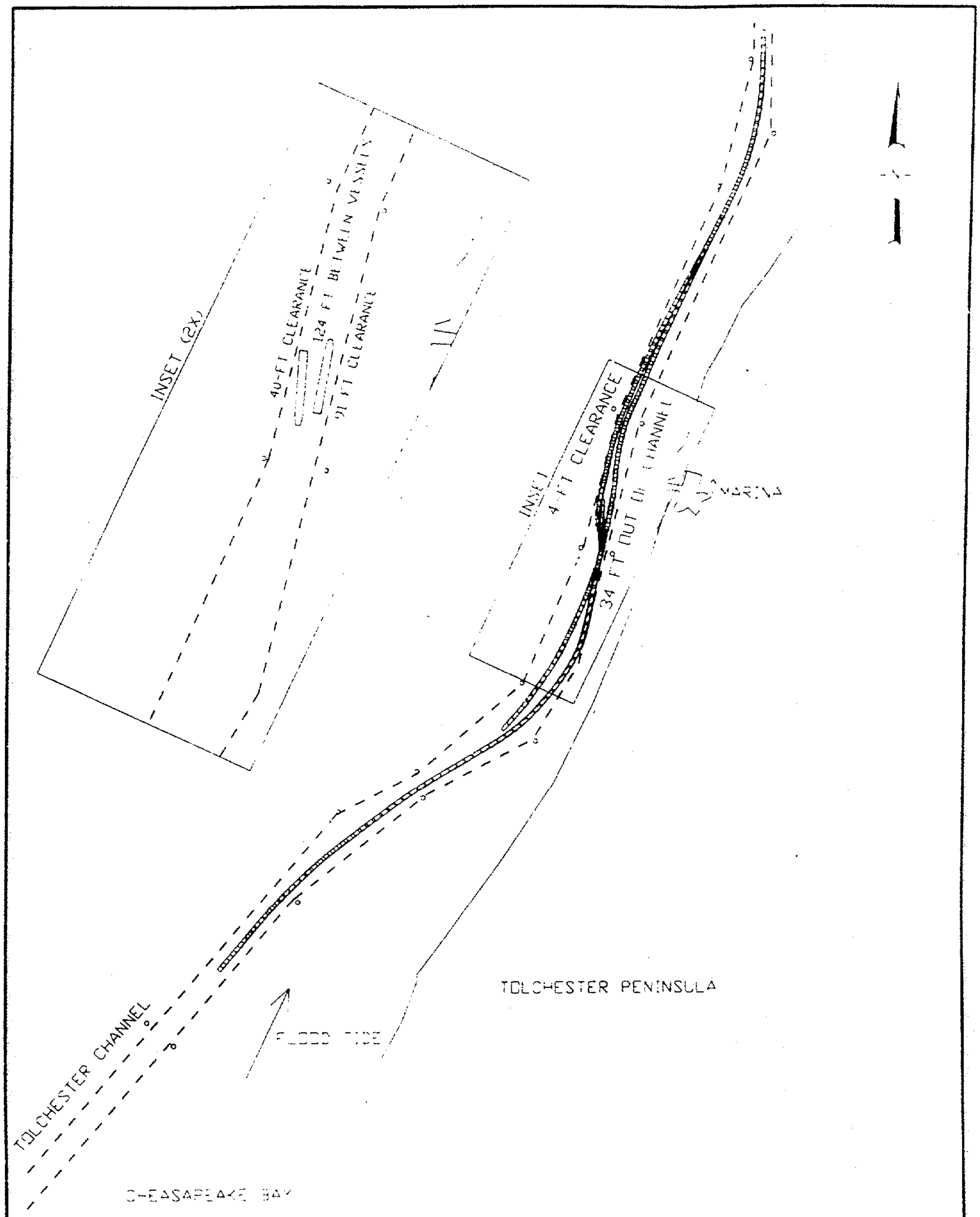
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 148

PRELIMINARY



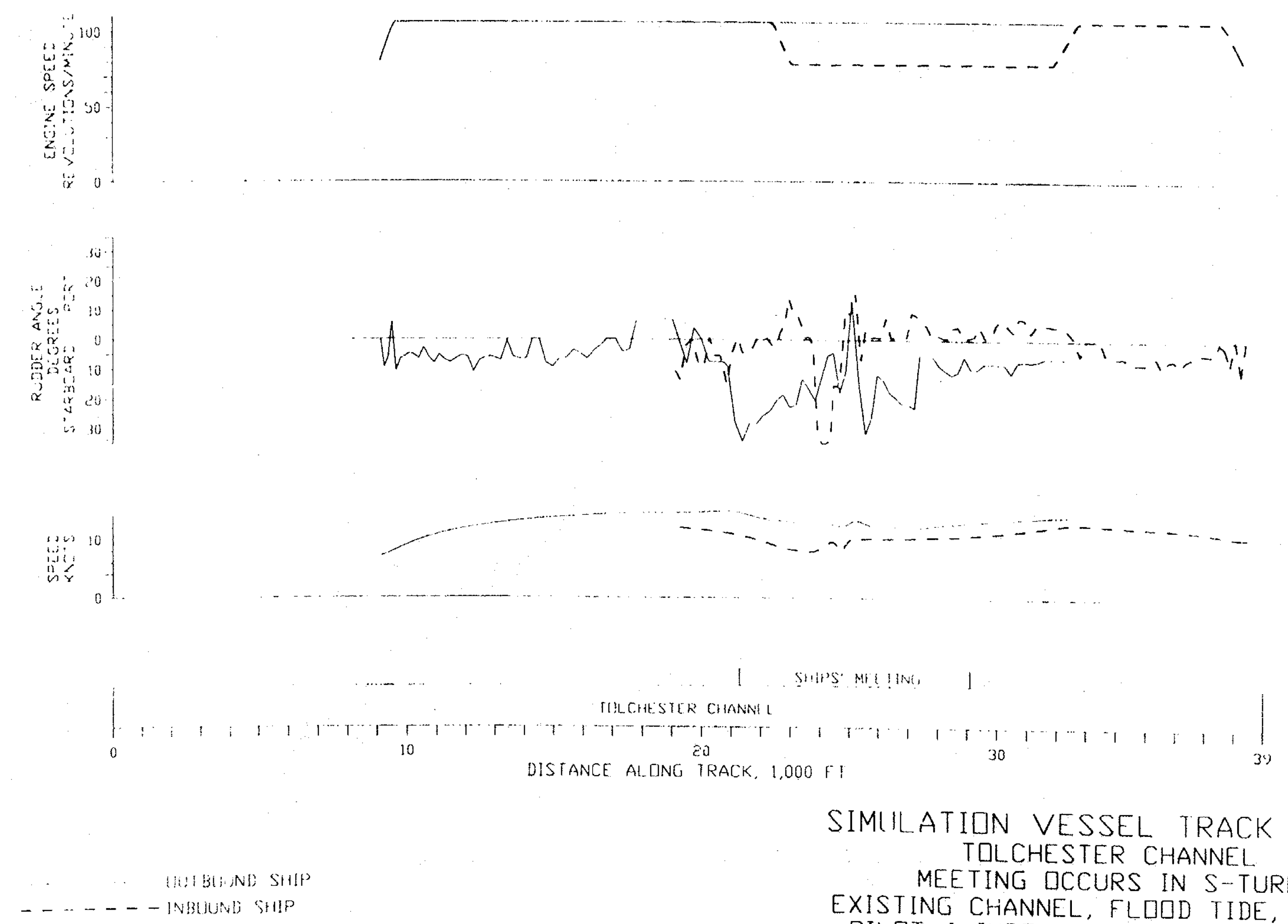
◦ CHANNEL MARKER

965- X 106- X 33-FT CONTAINER SHIP

SCALE IN FEET
0 2000

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

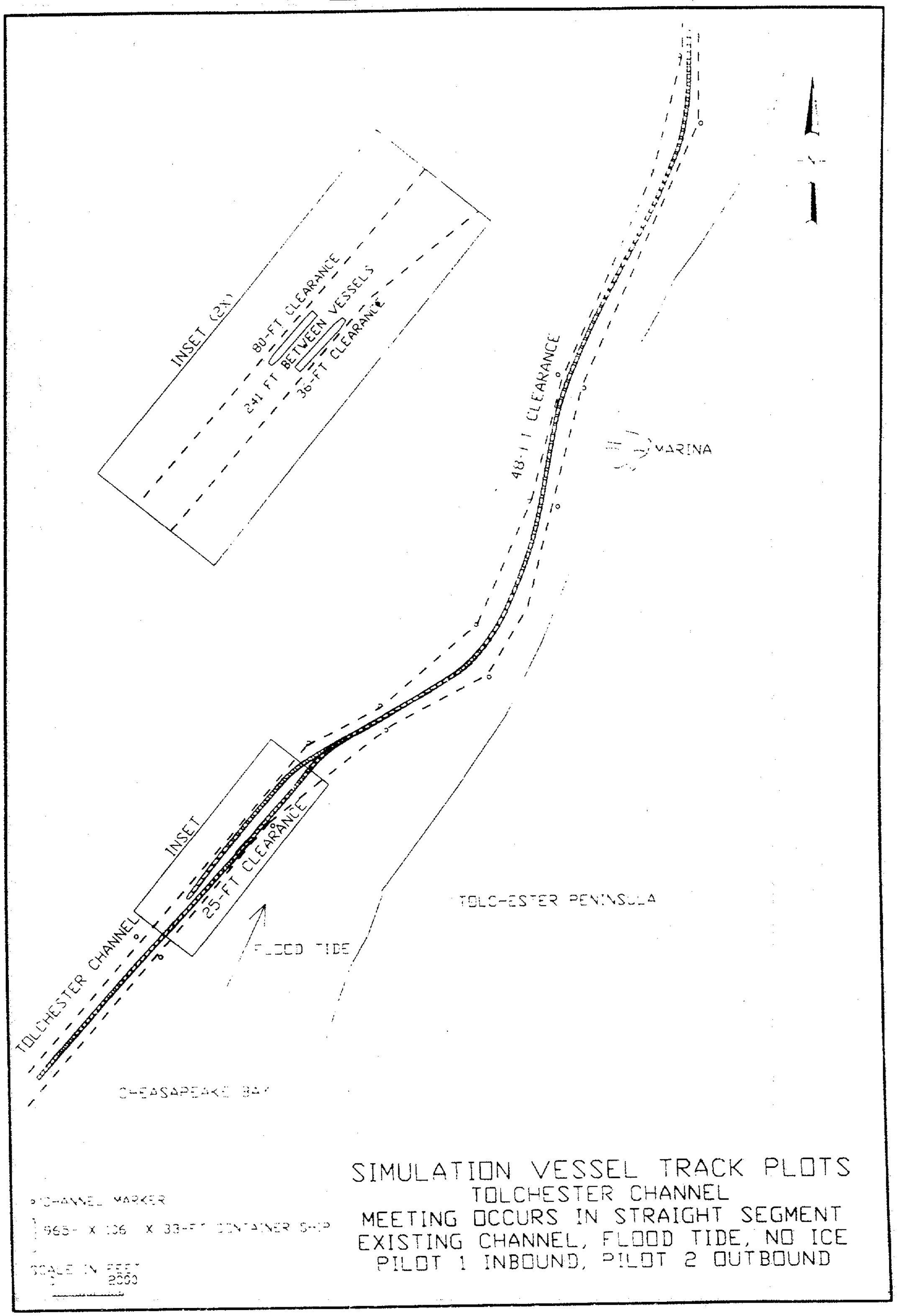
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 150

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

PRELIMINARY

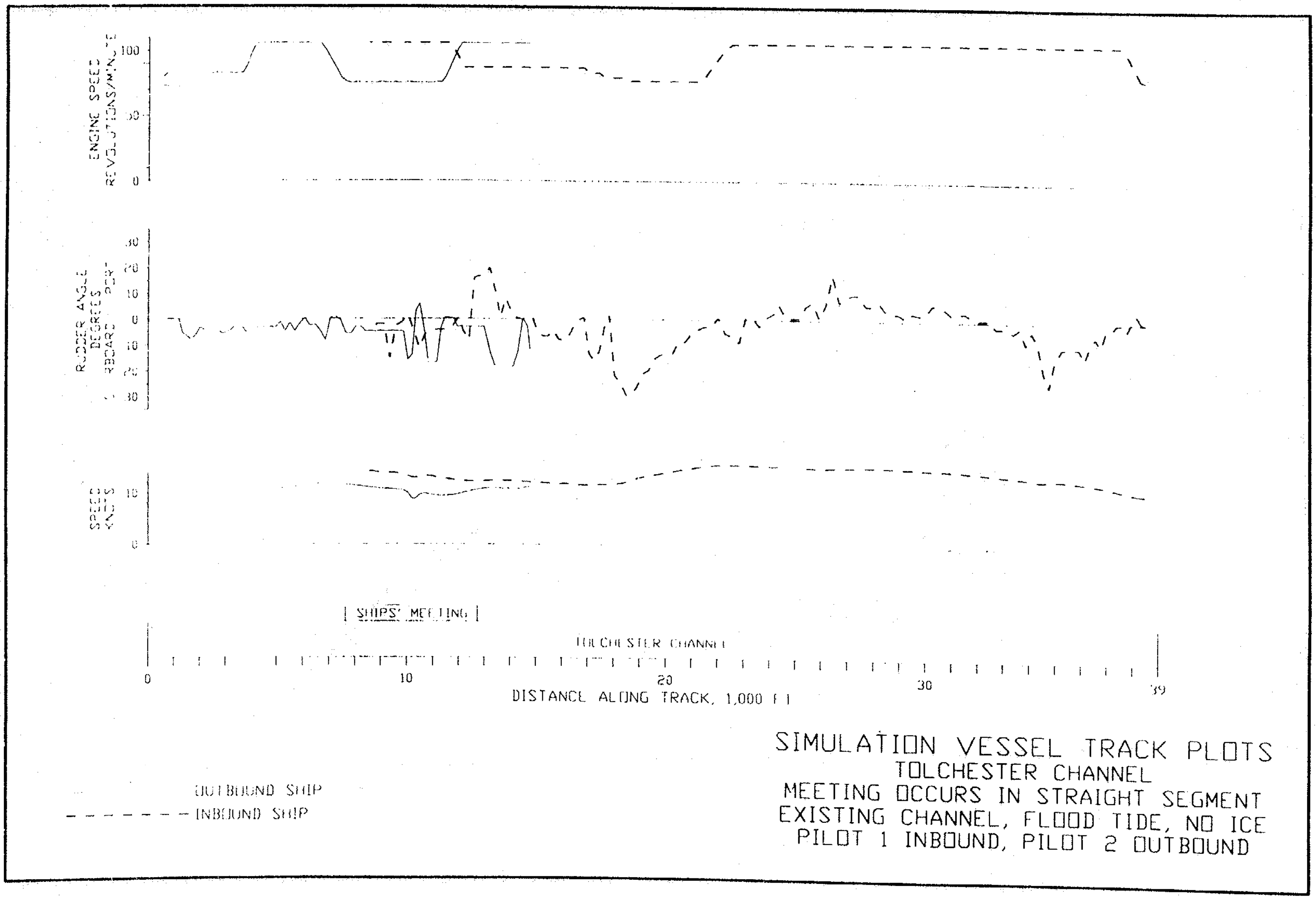
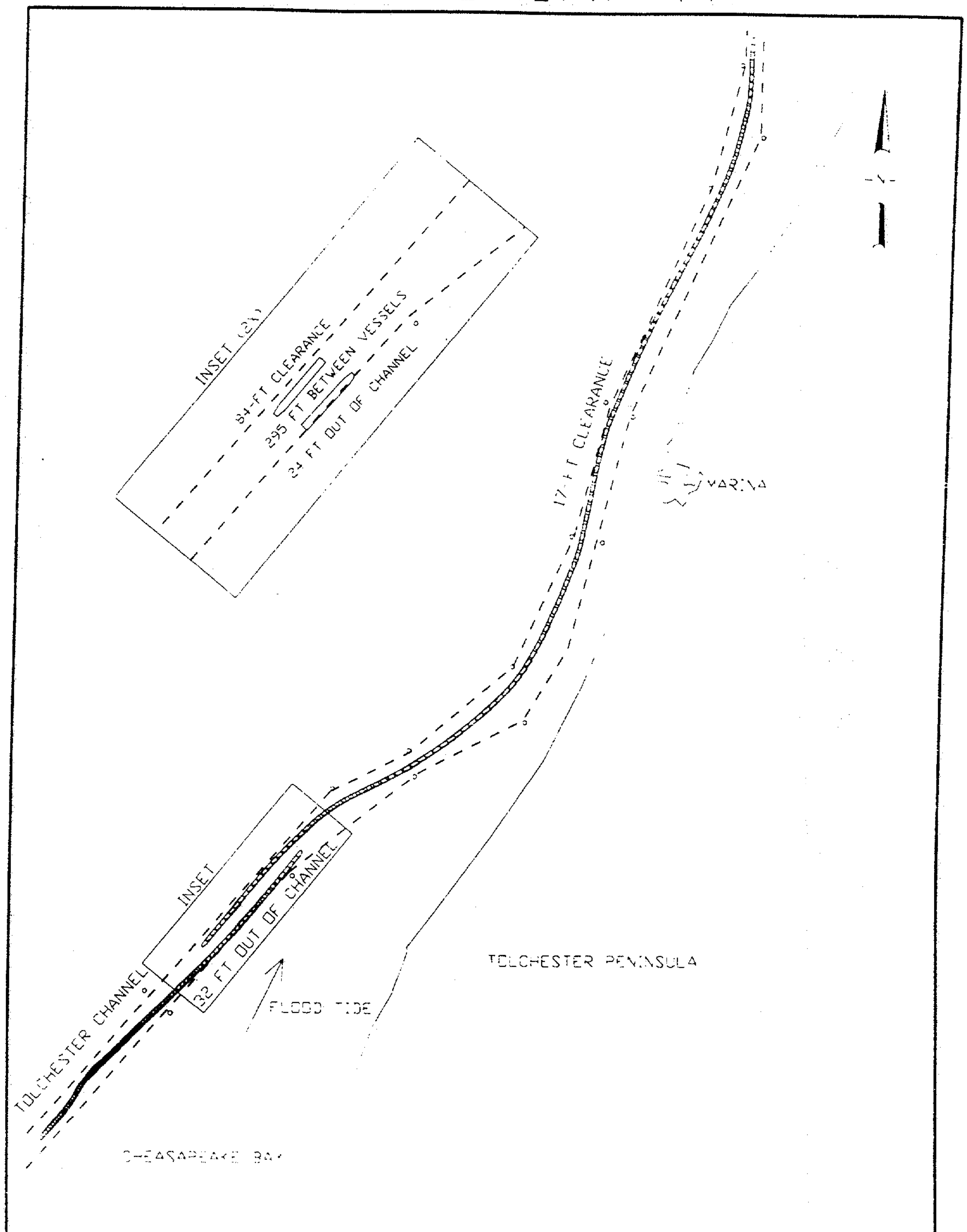


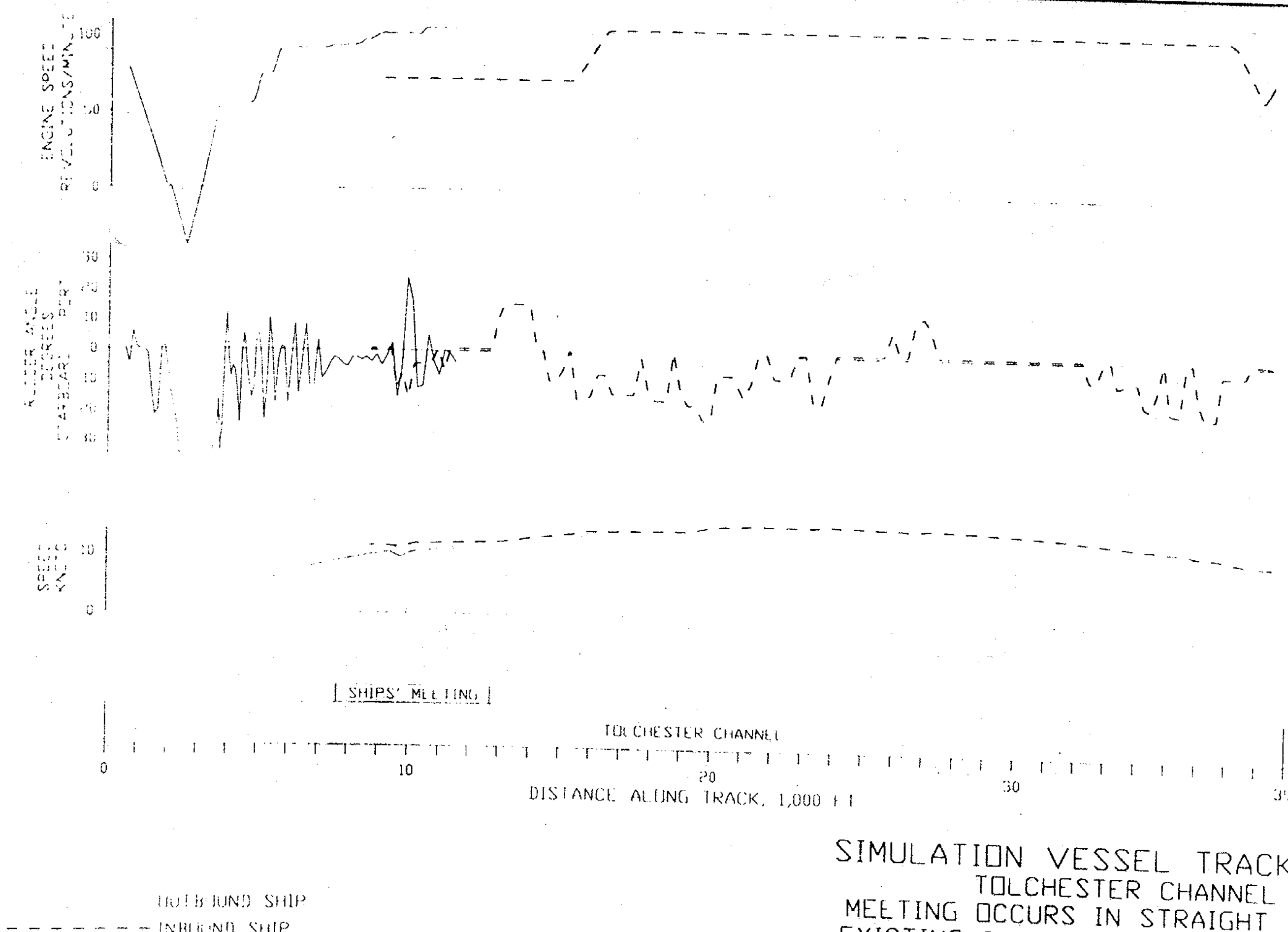
Plate 152

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 154

PRELIMINARY

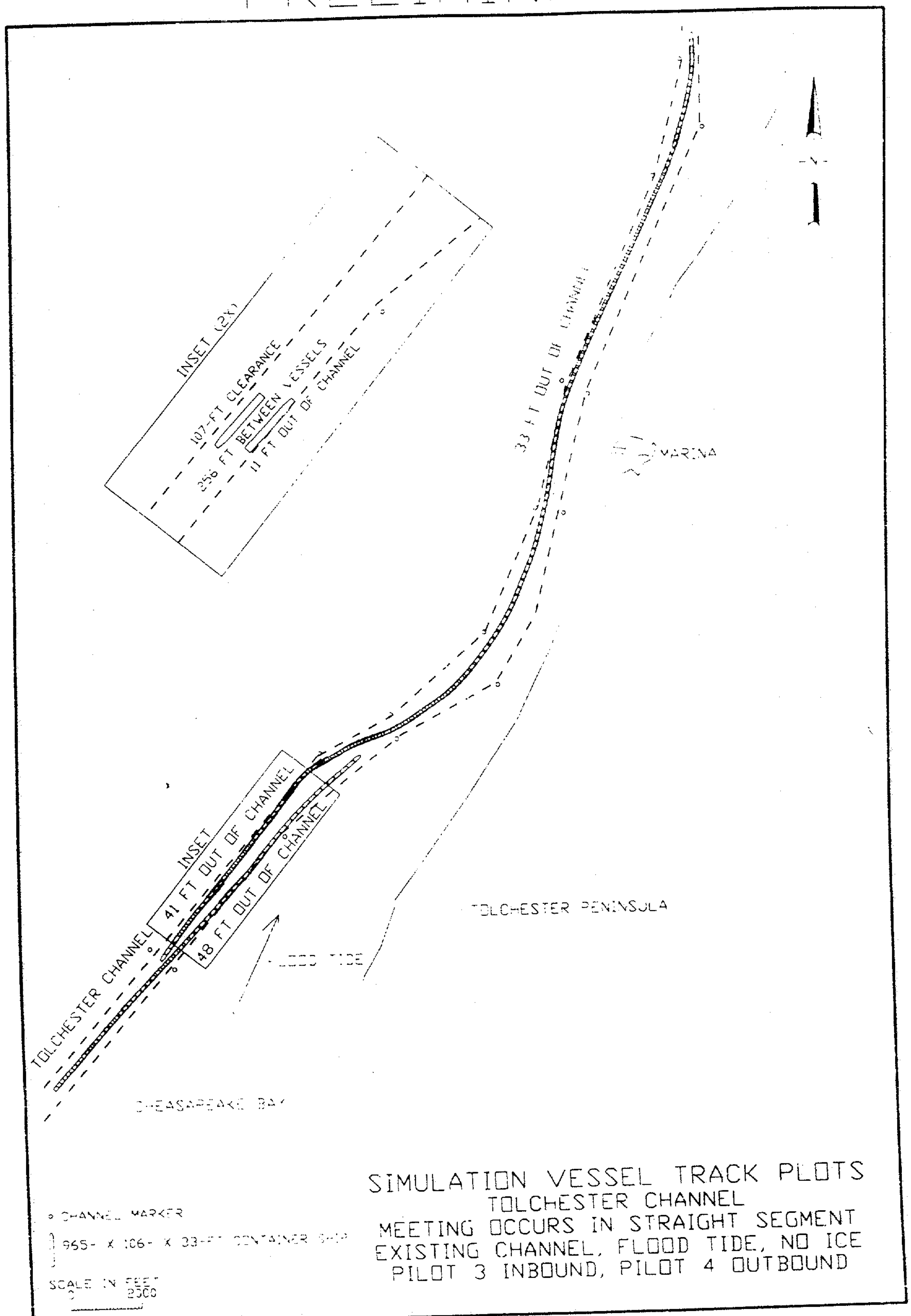
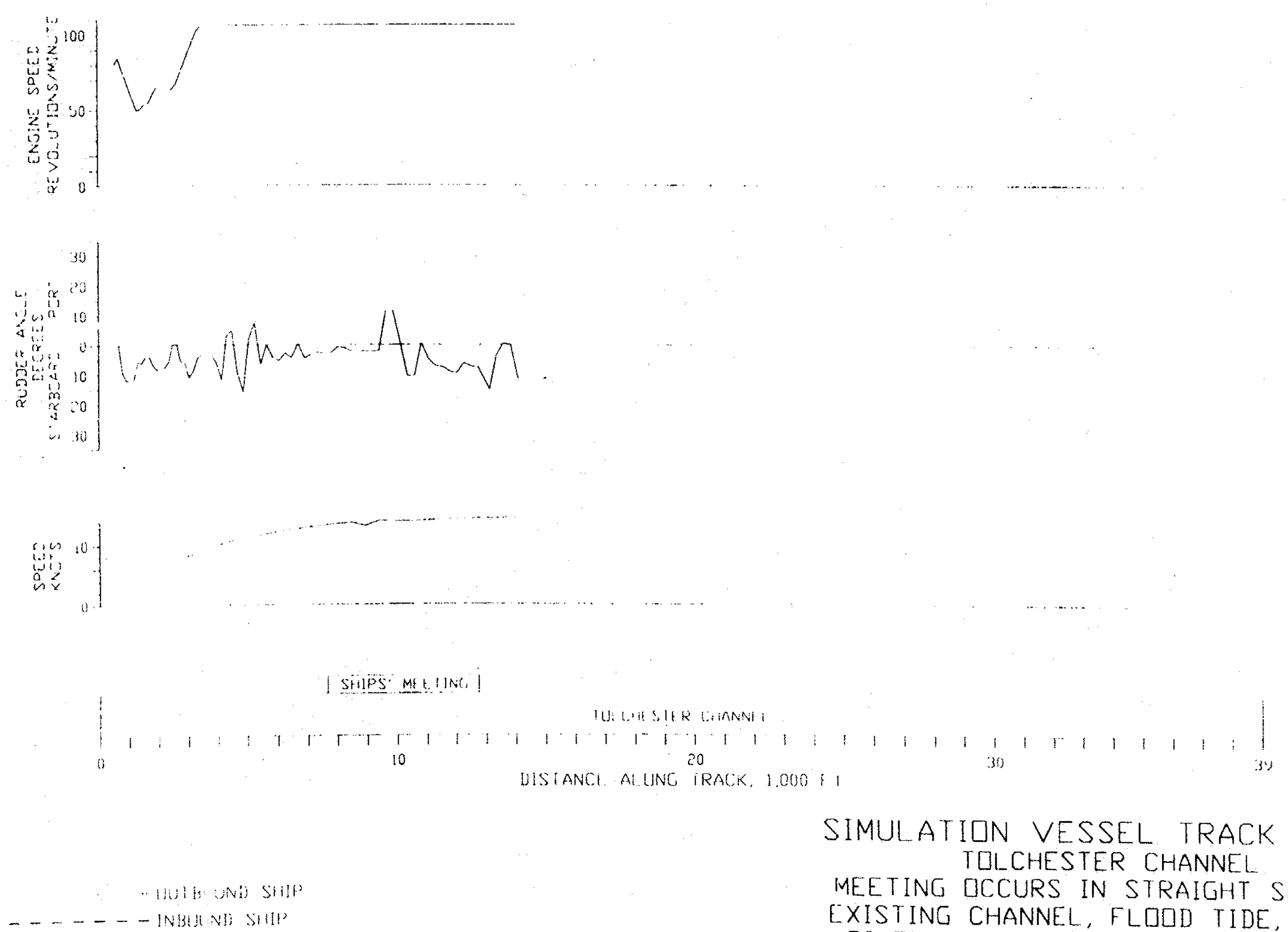


Plate 155

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 156

PRELIMINARY

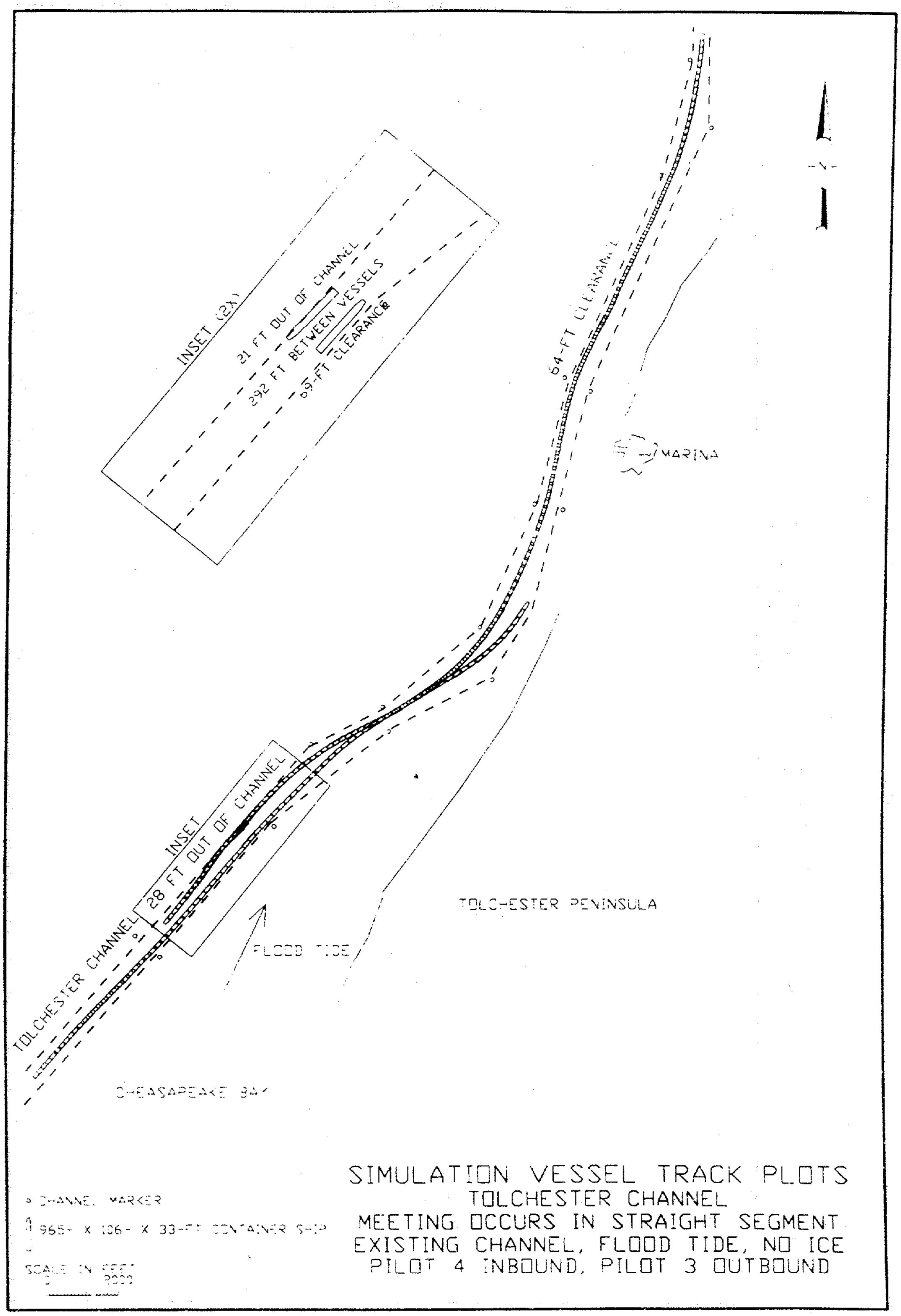
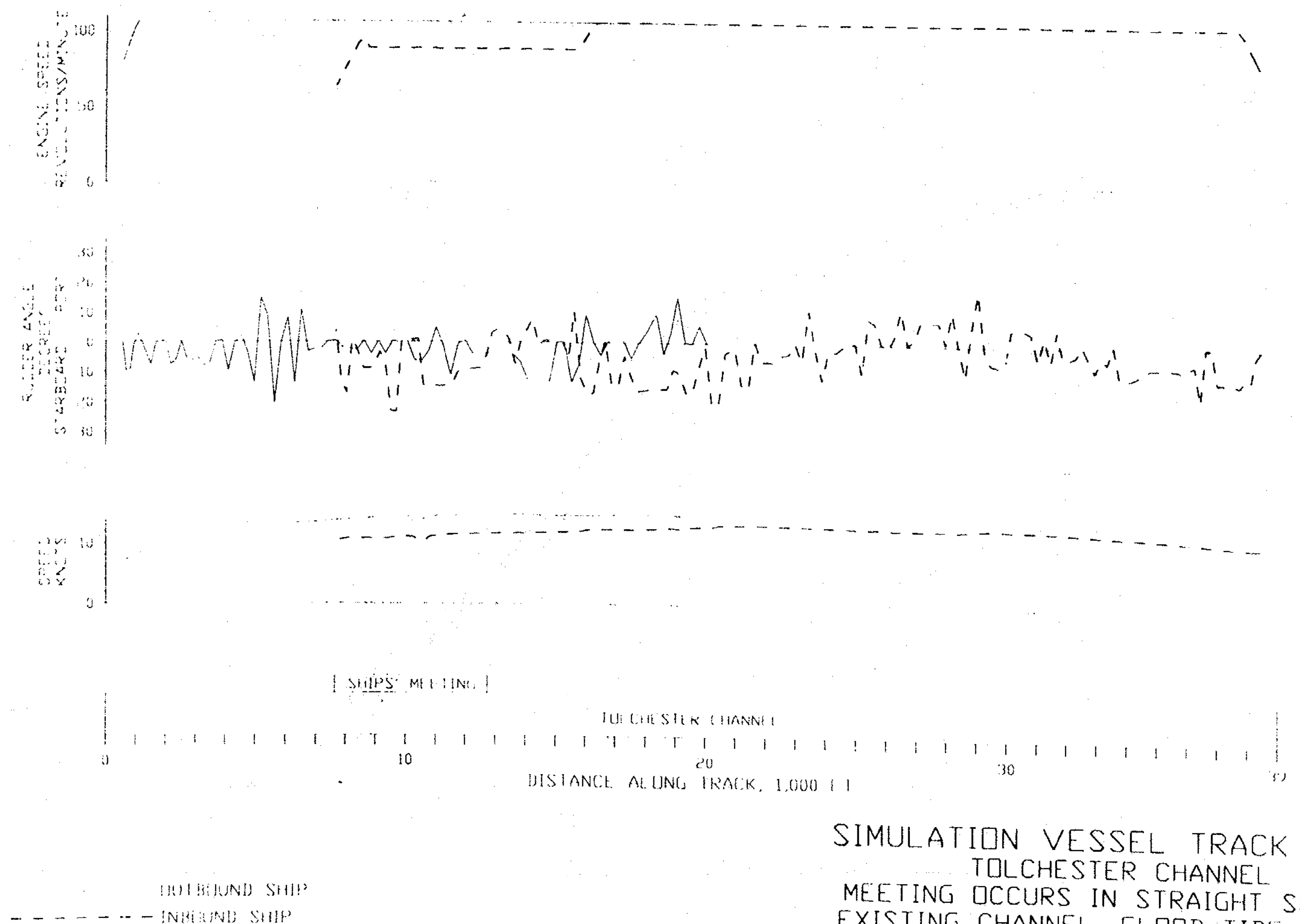


Plate 157

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 158

PRELIMINARY

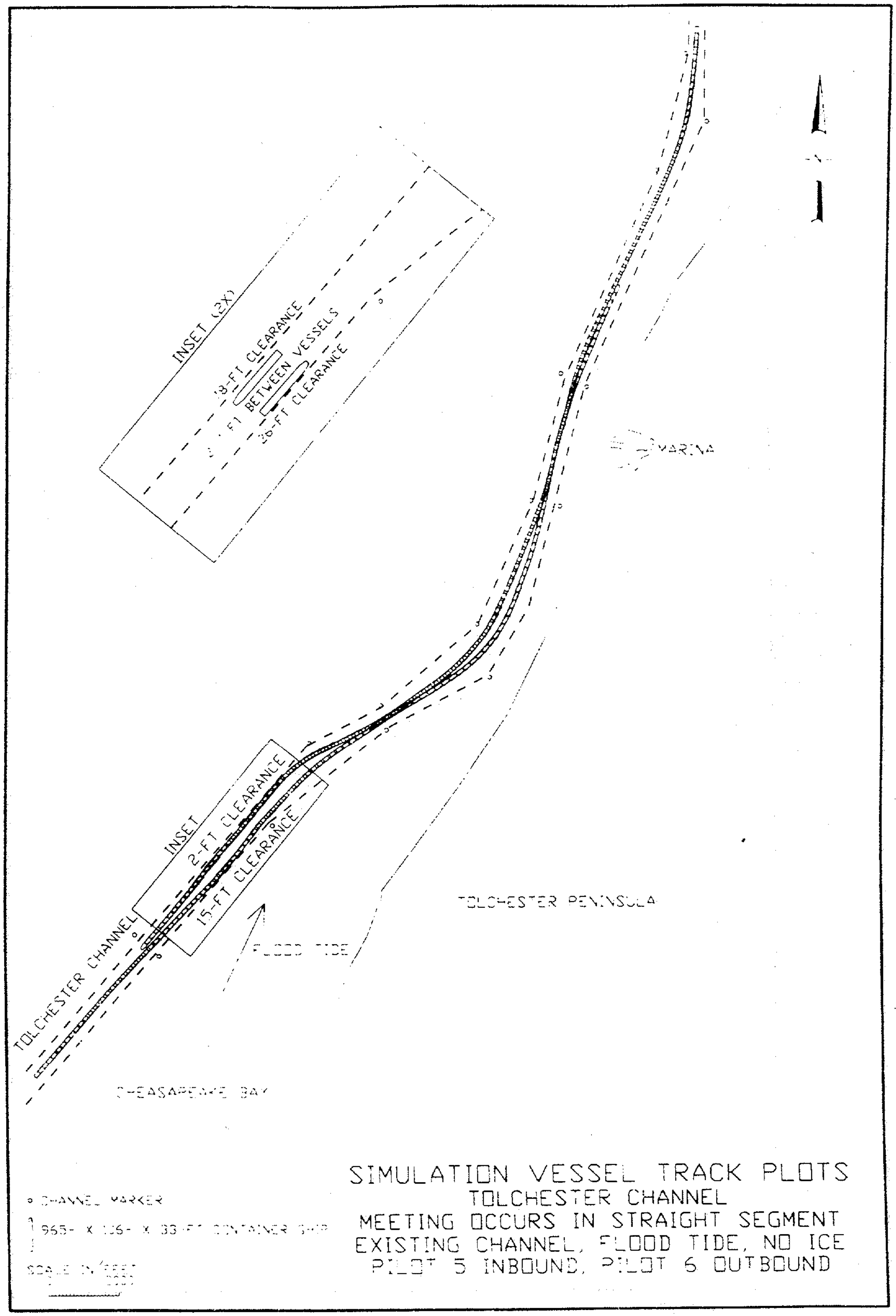
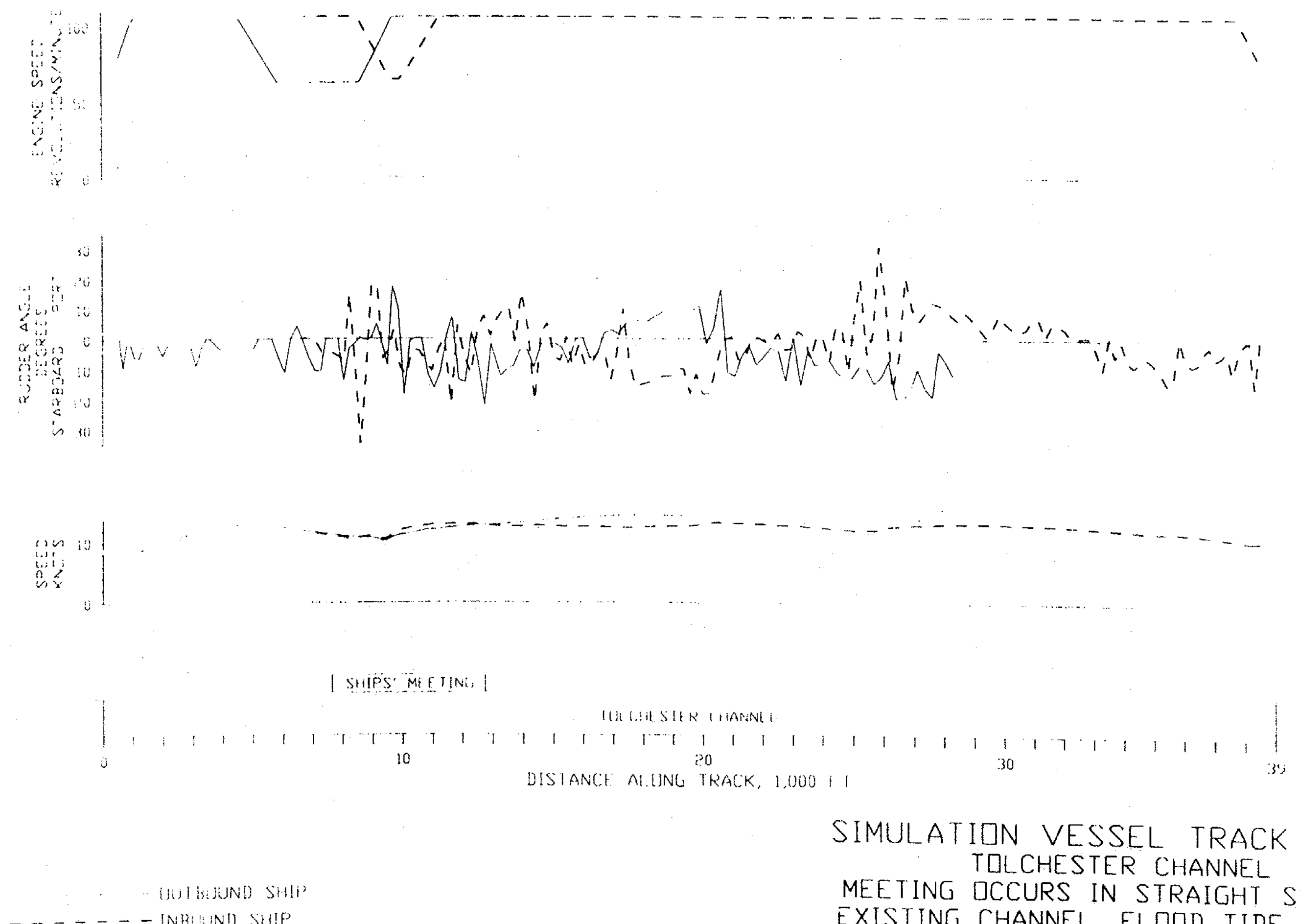


Plate 159

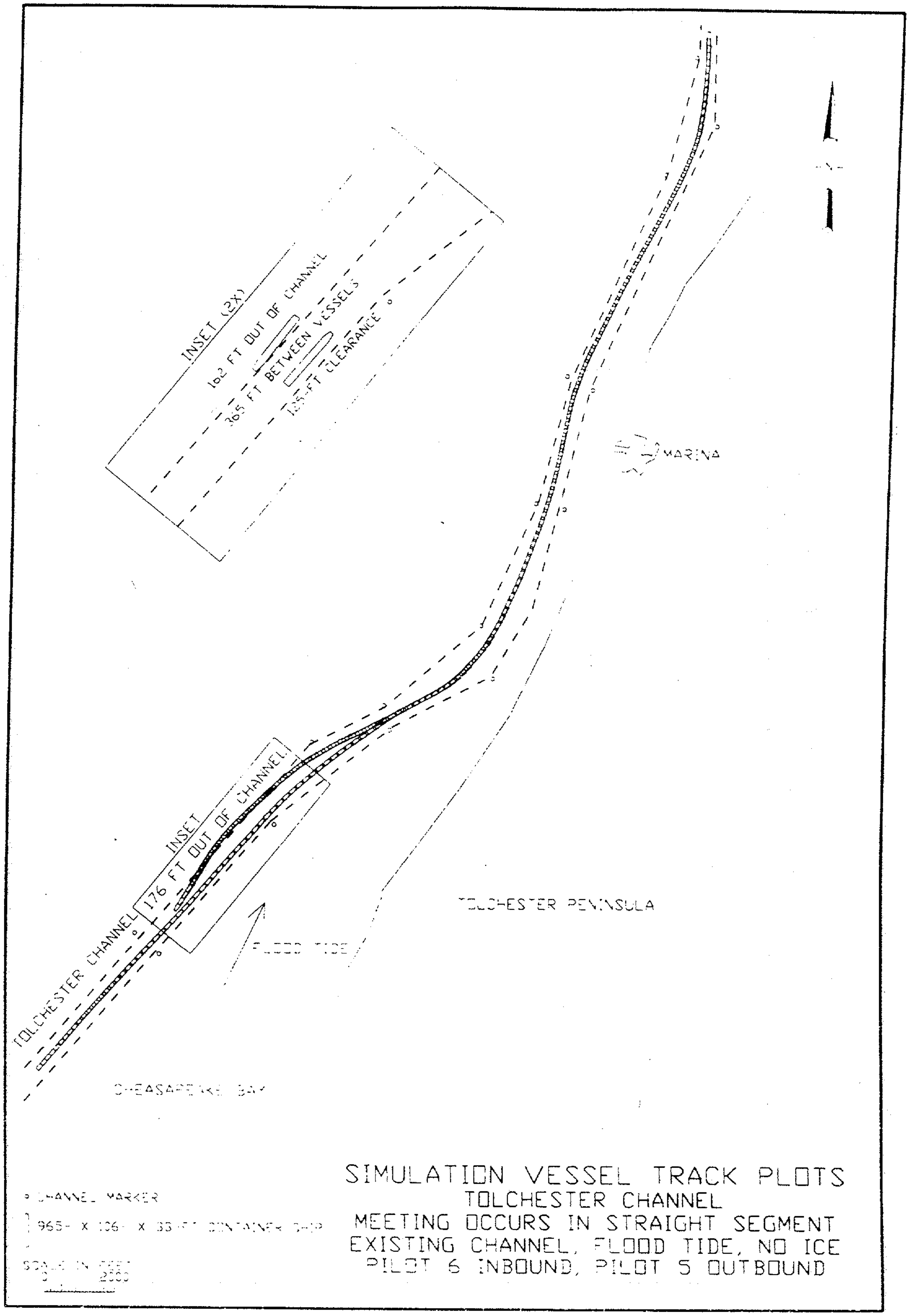
PRELIMINARY



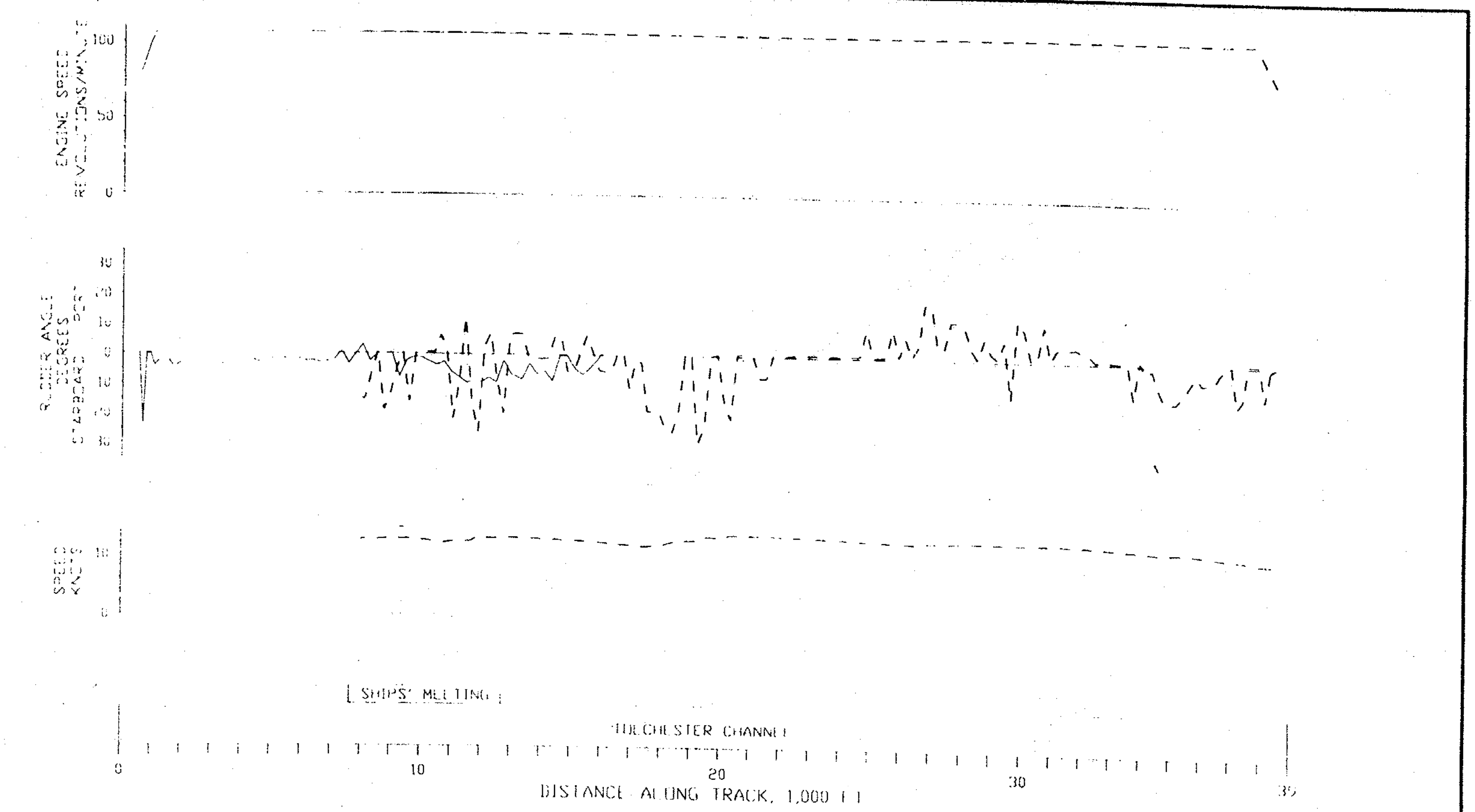
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 160

PRELIMINARY



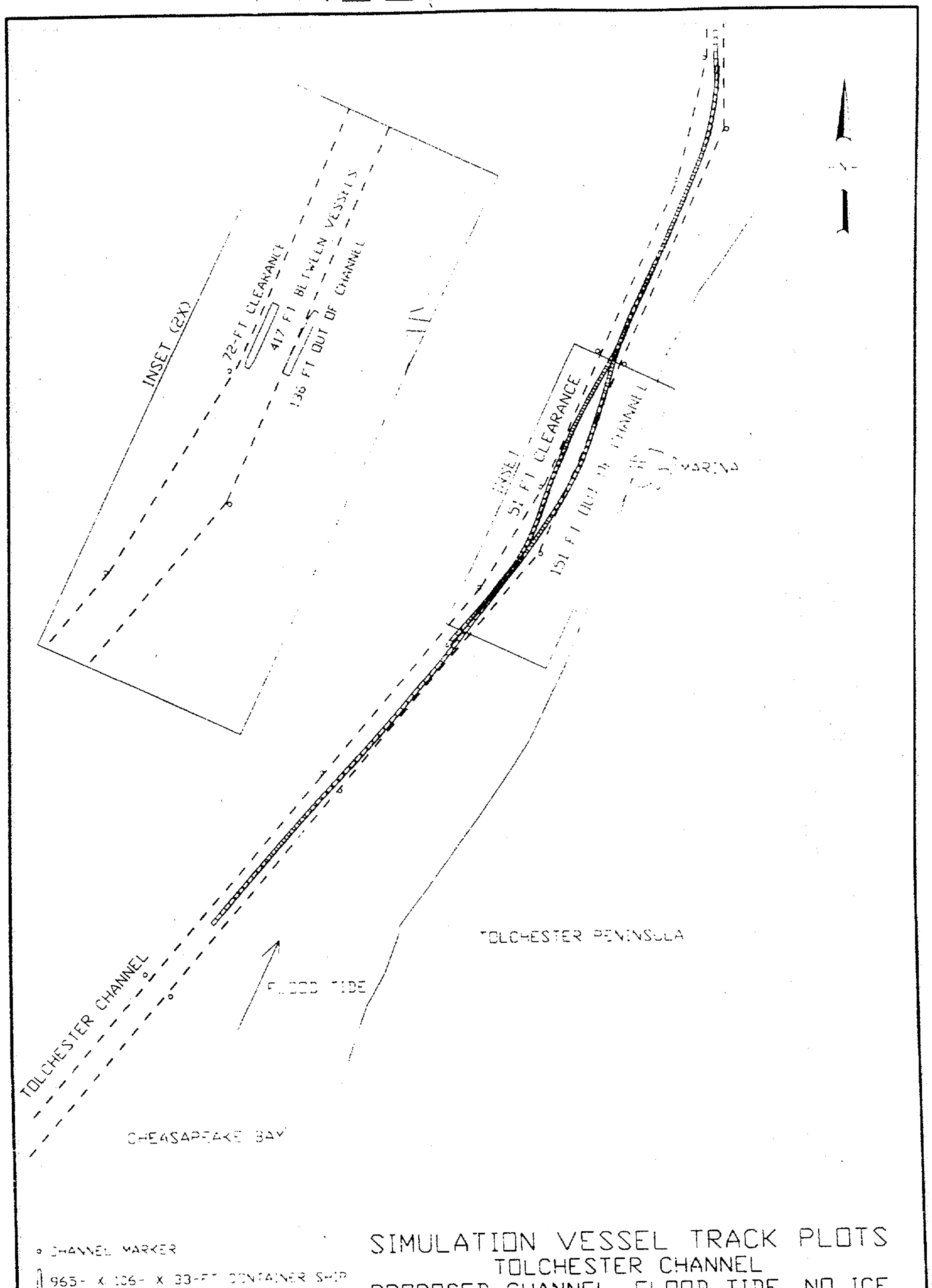
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 162

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 163

PRELIMINARY

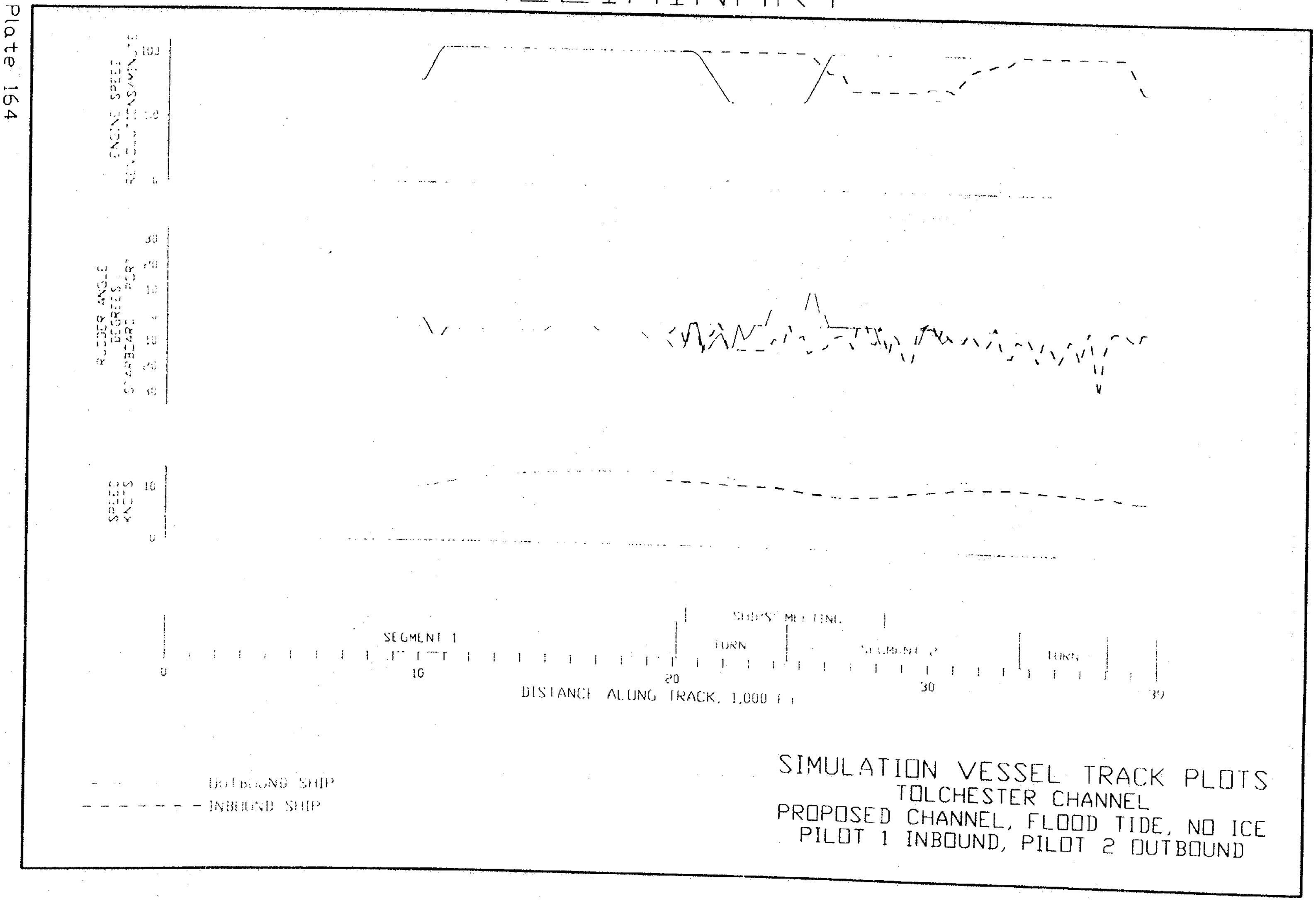
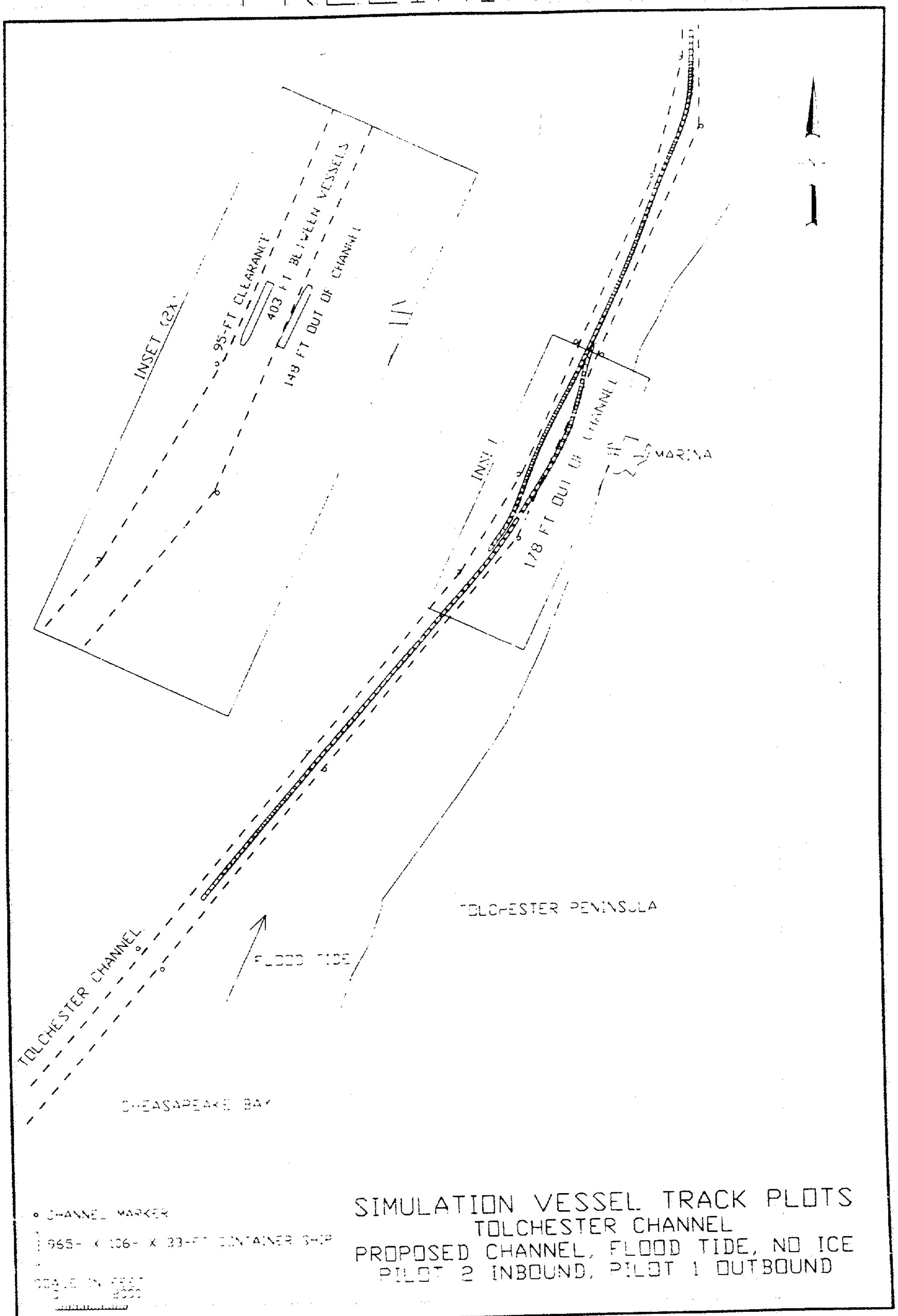


Plate 164

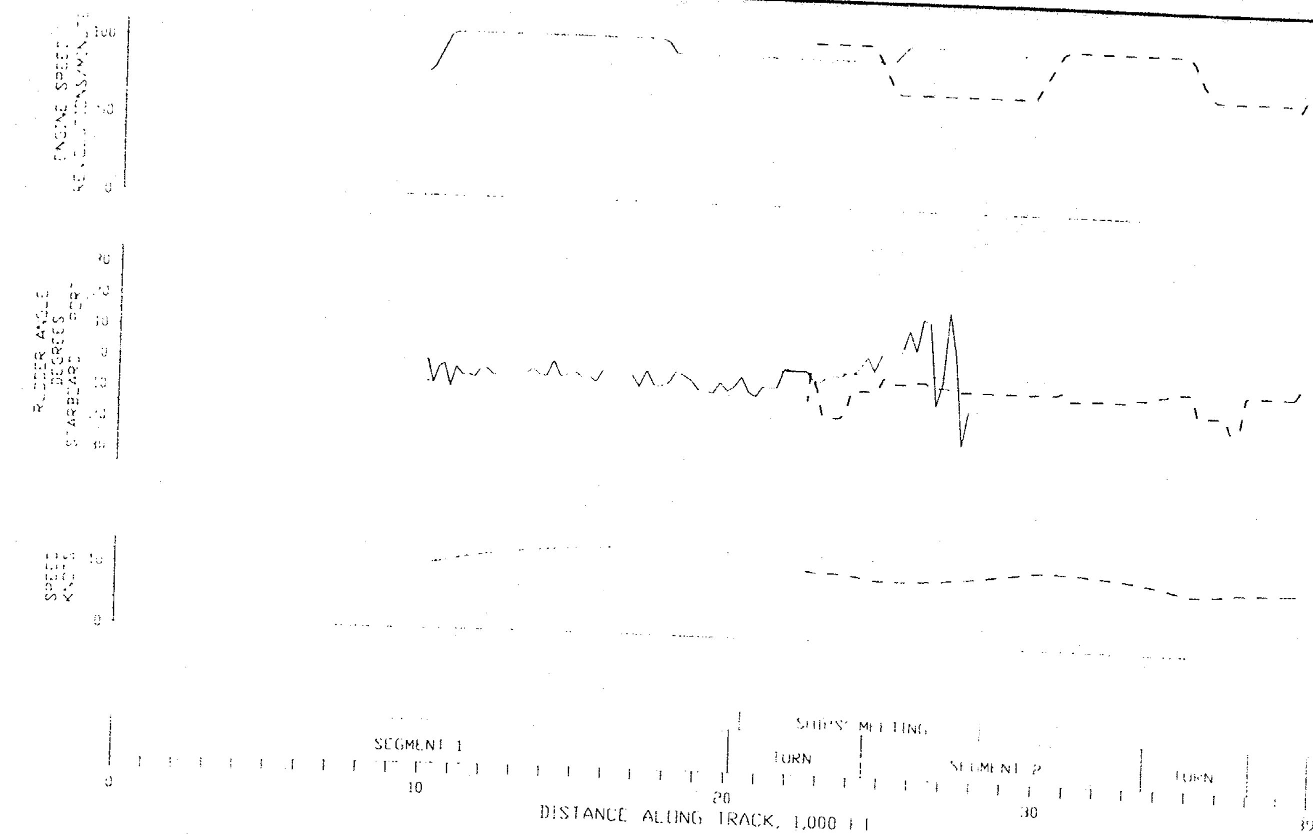
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 165

PRELIMINARY

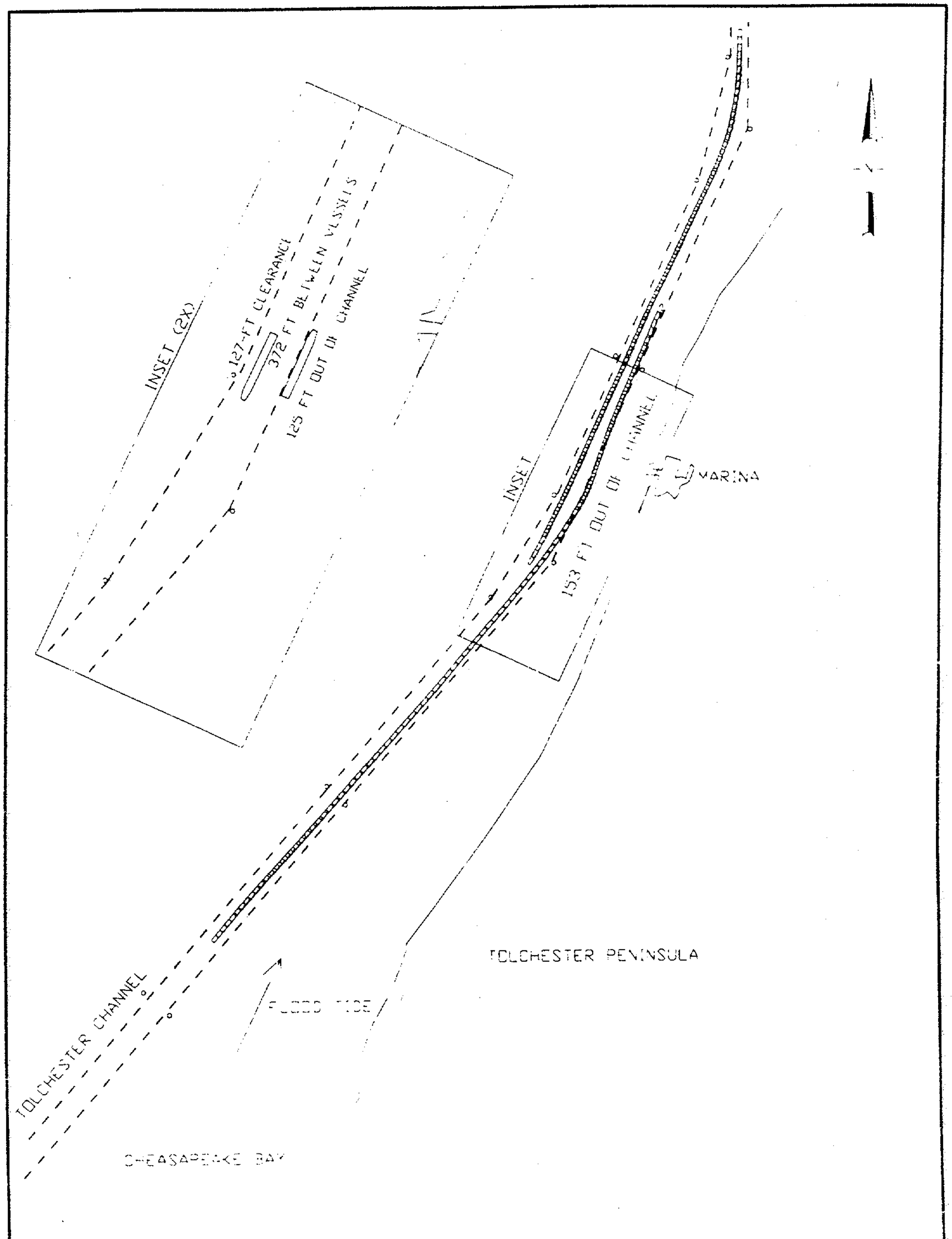


OUTBOUND SHIP
- - - - - - INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 166

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY

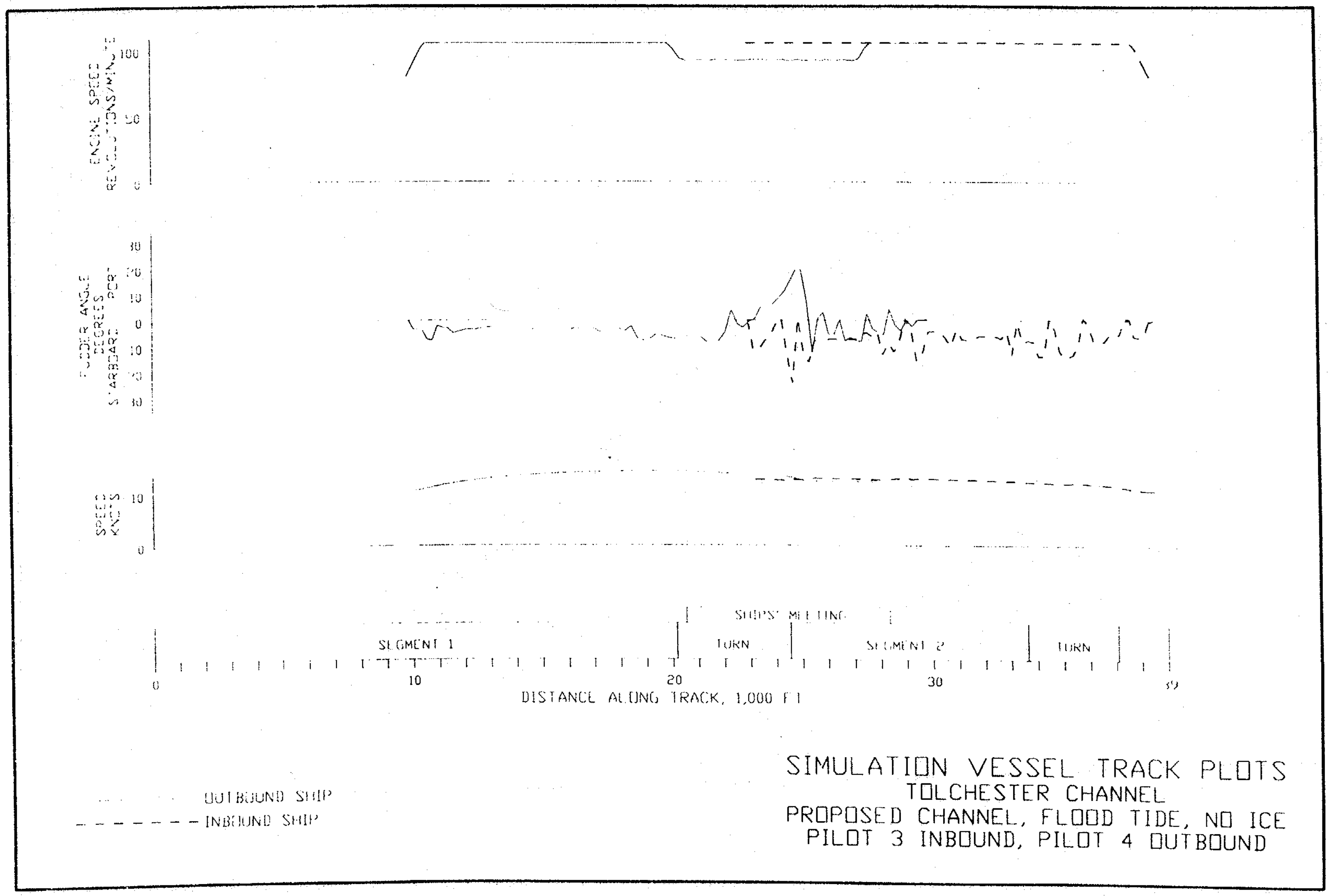
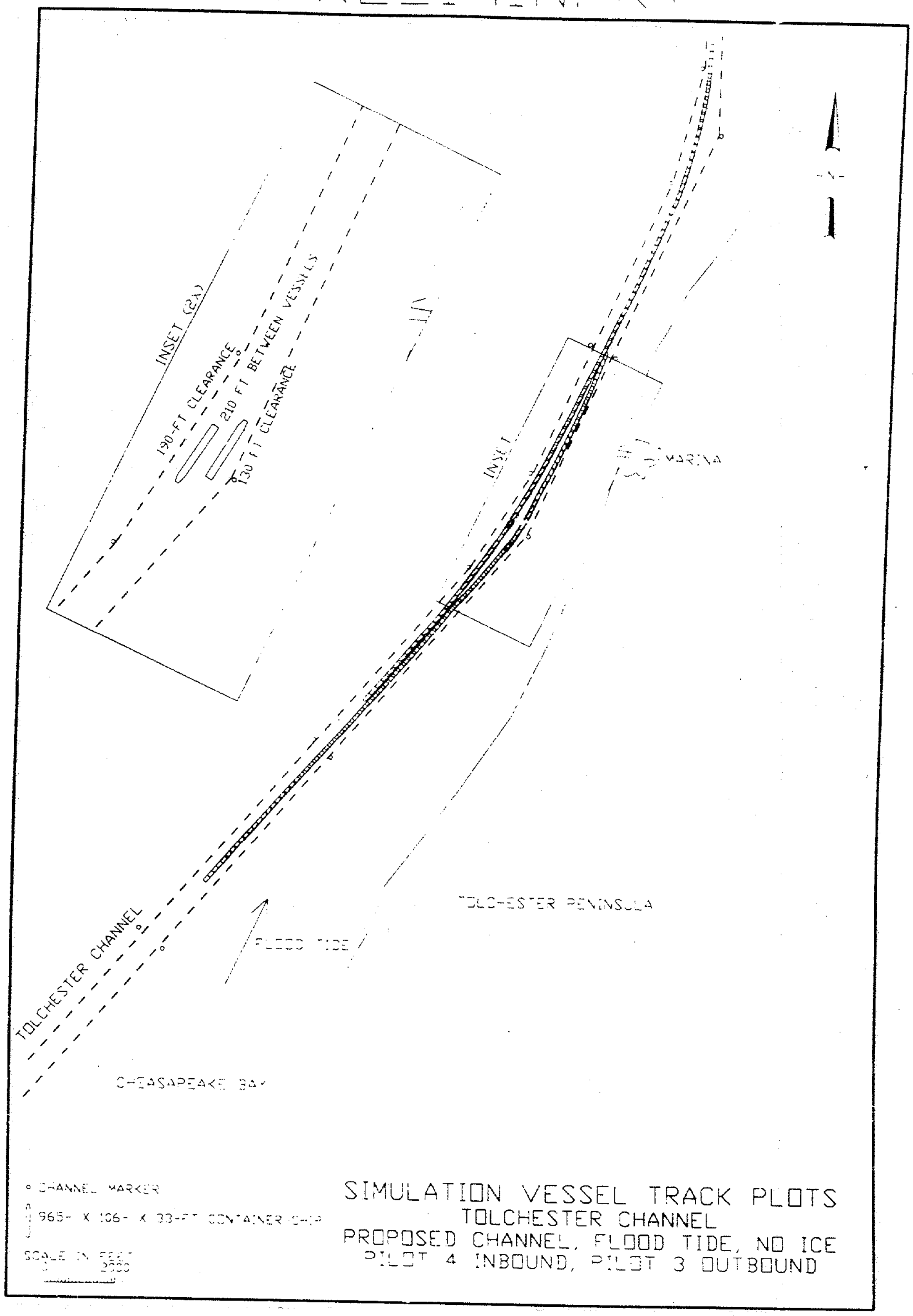


Plate 168

PRELIMINARY



PRELIMINARY

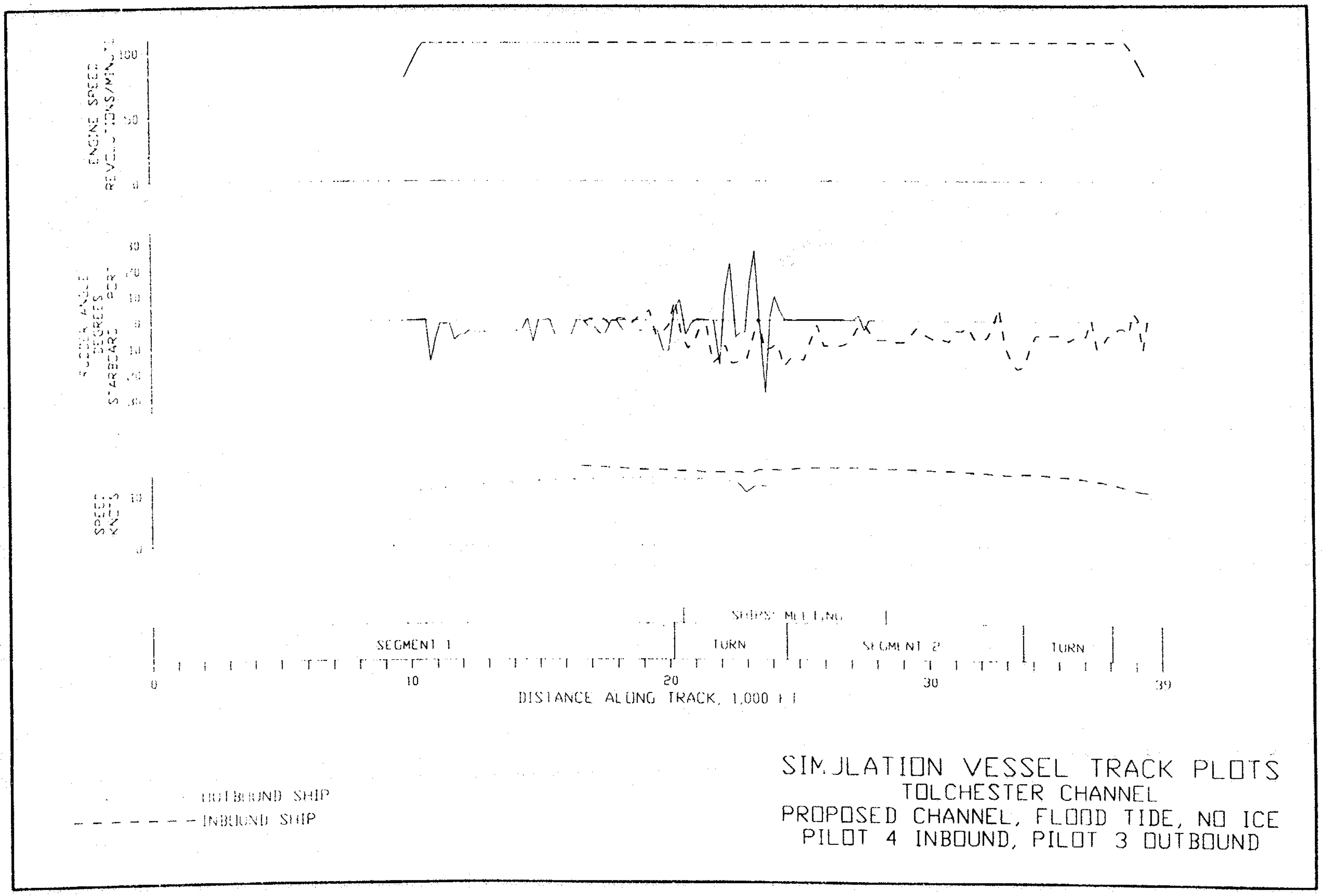
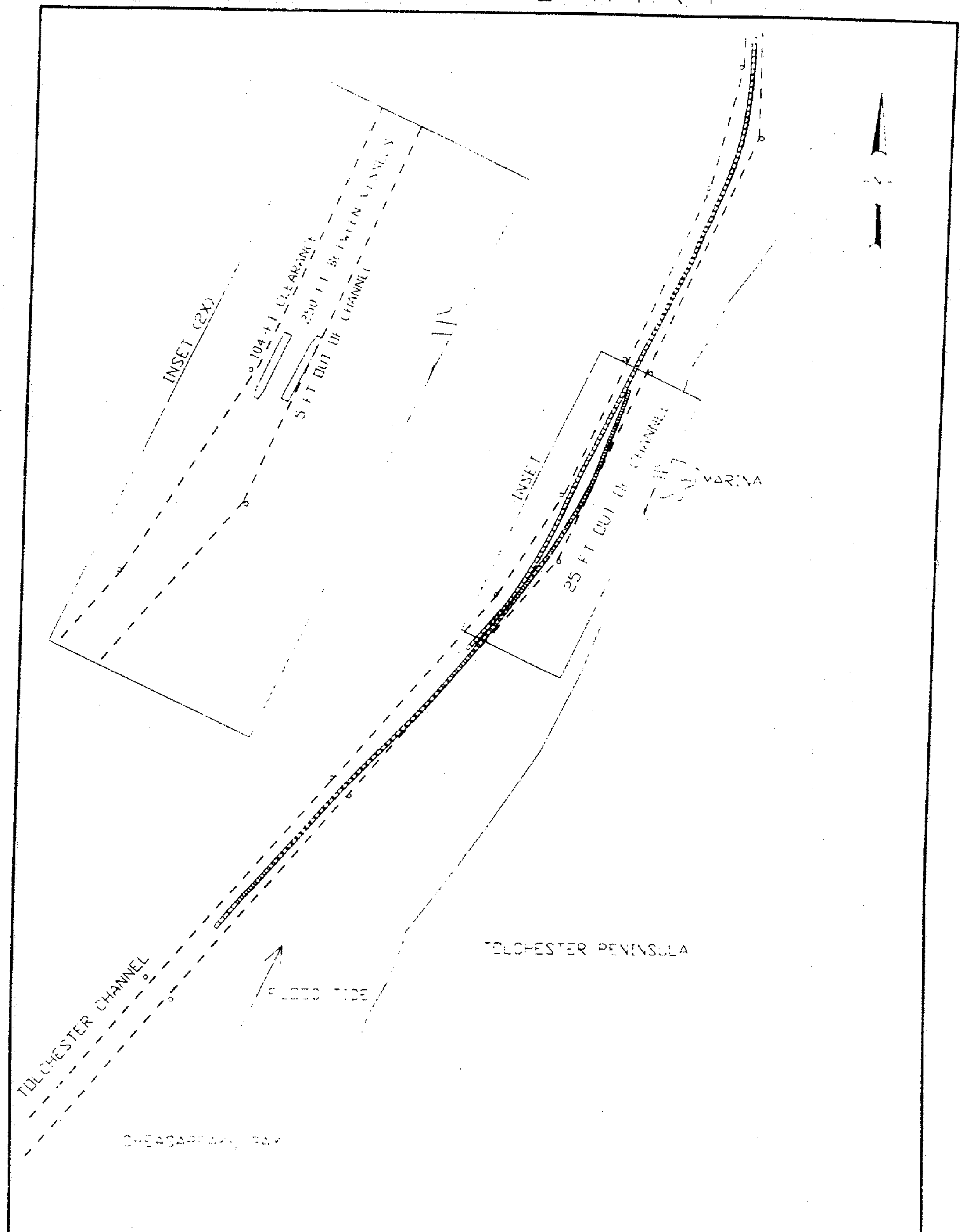


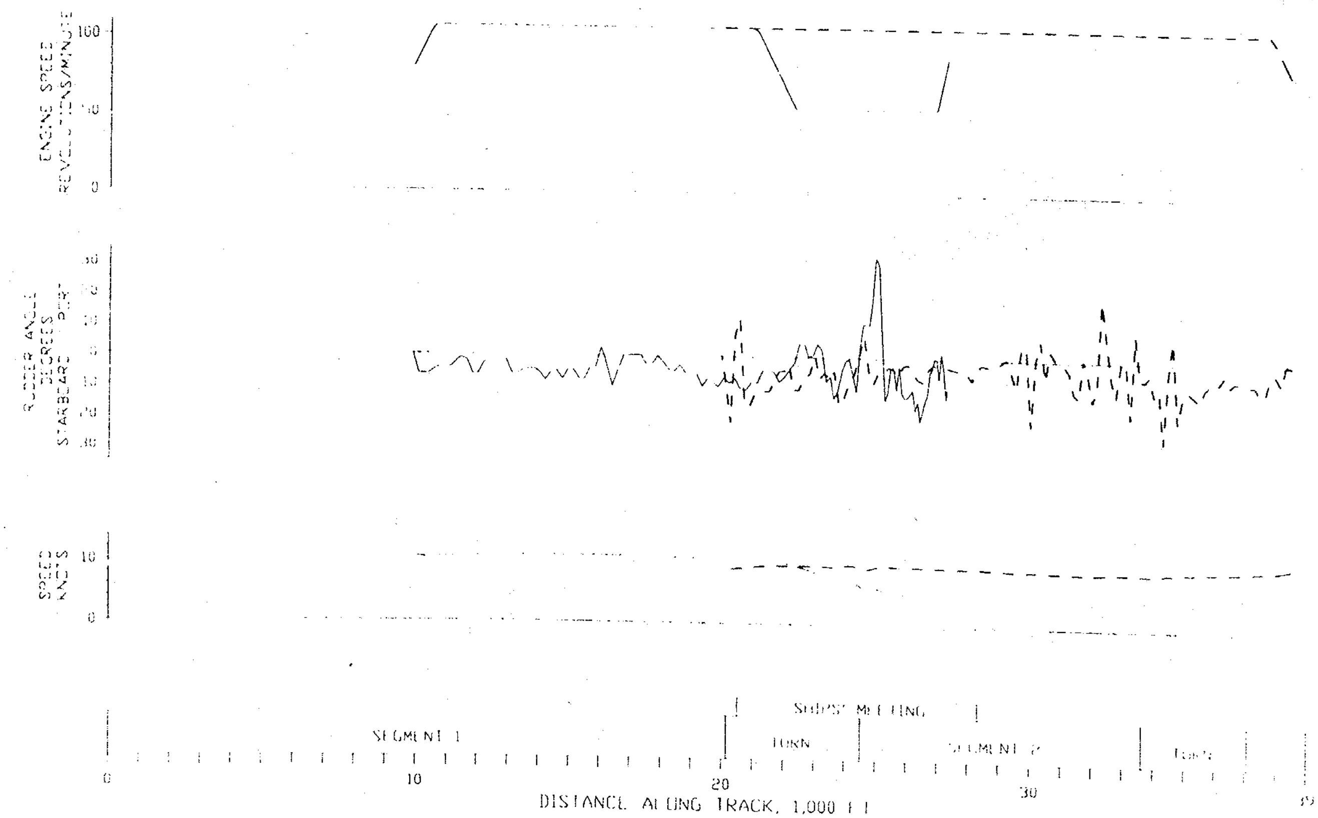
Plate 170

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

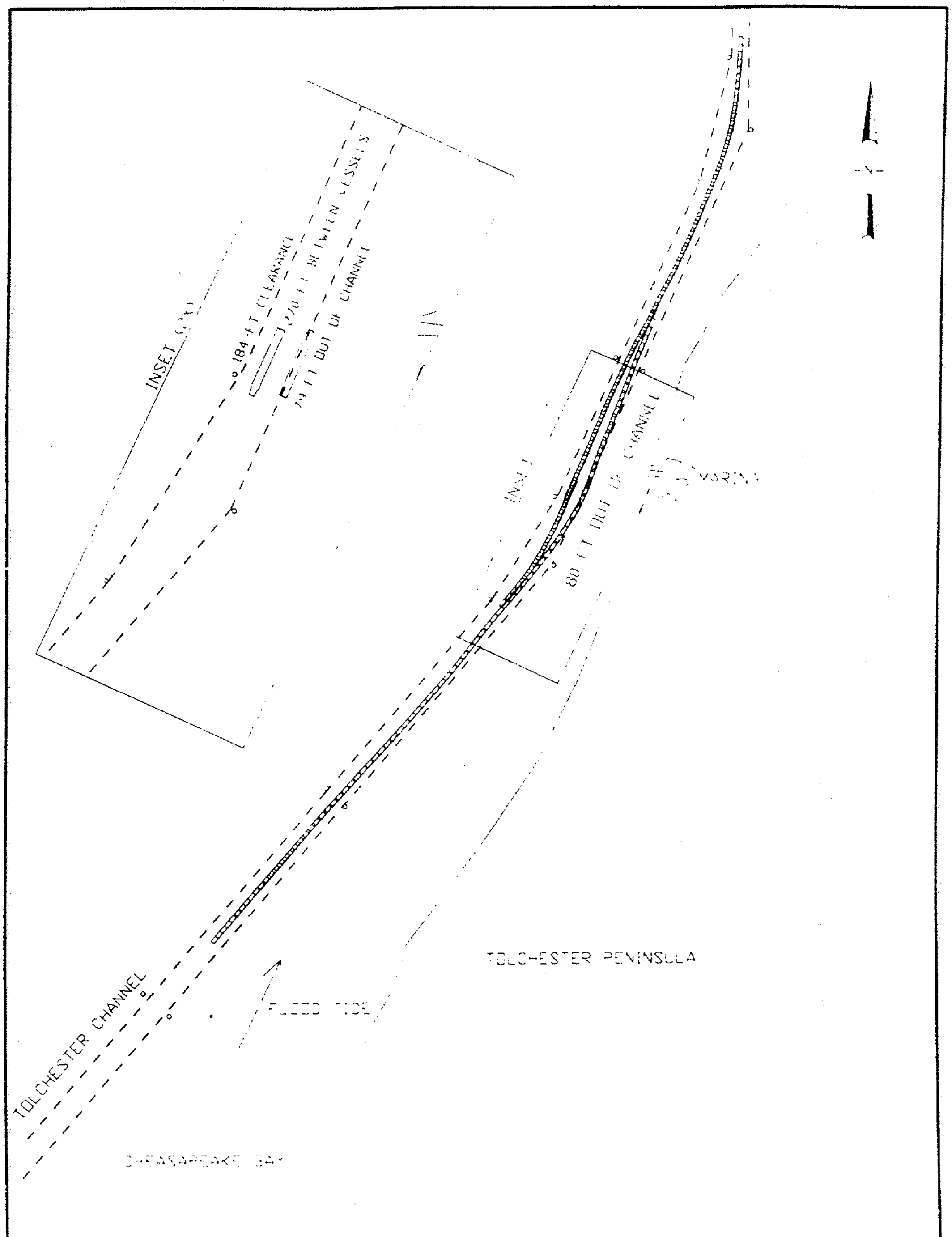
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 172

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, NO ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

PRELIMINARY

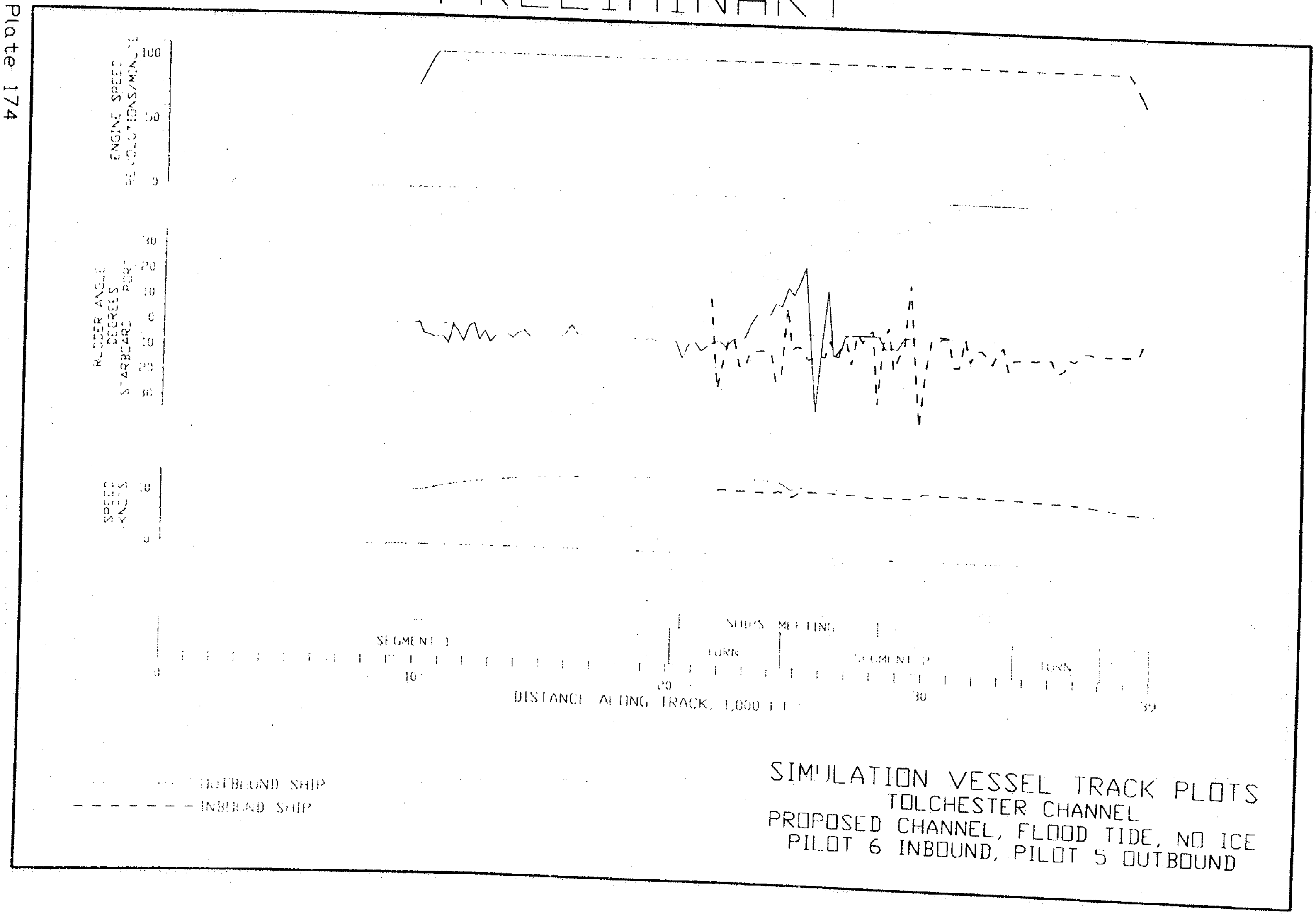
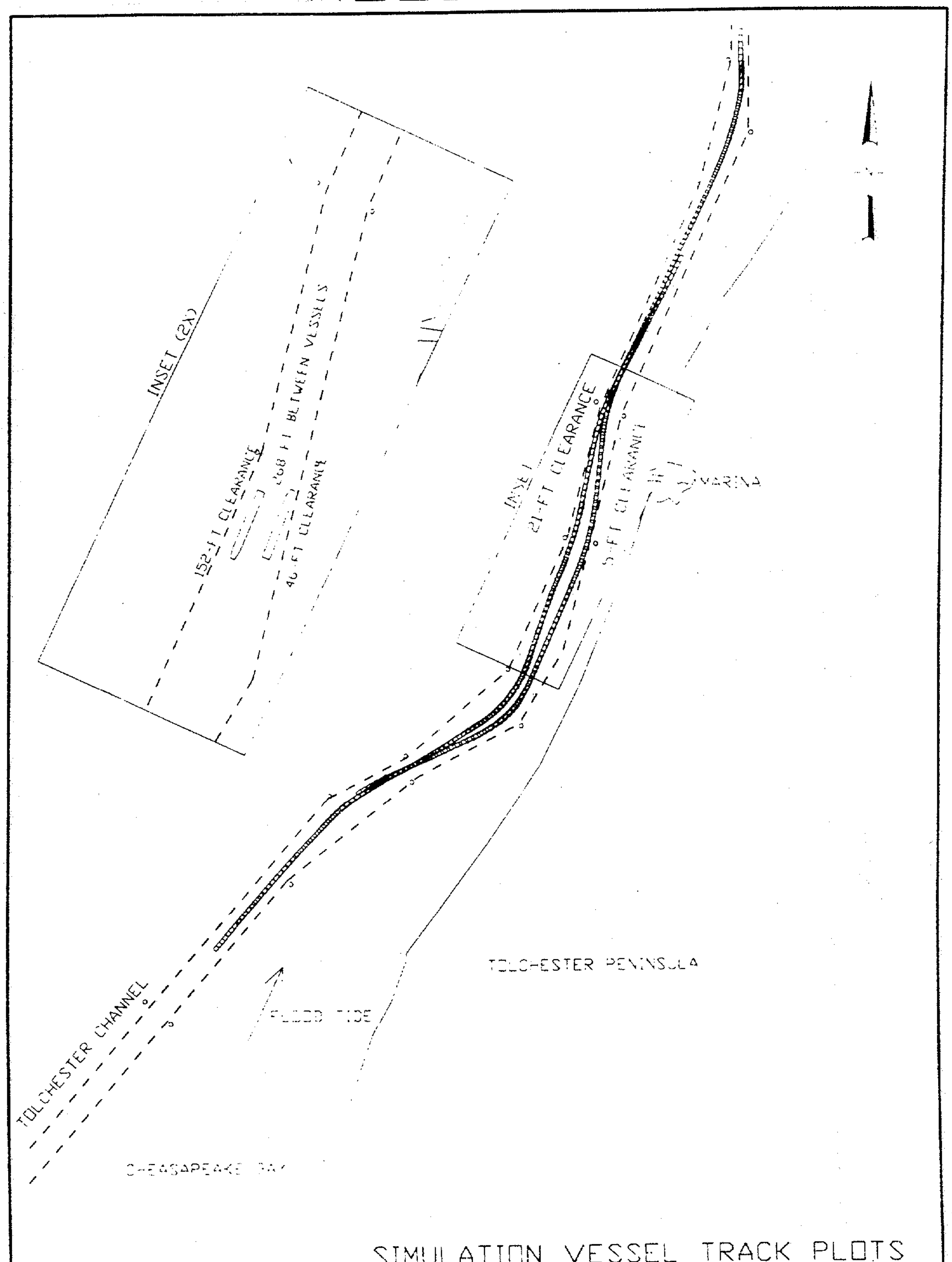


Plate 174

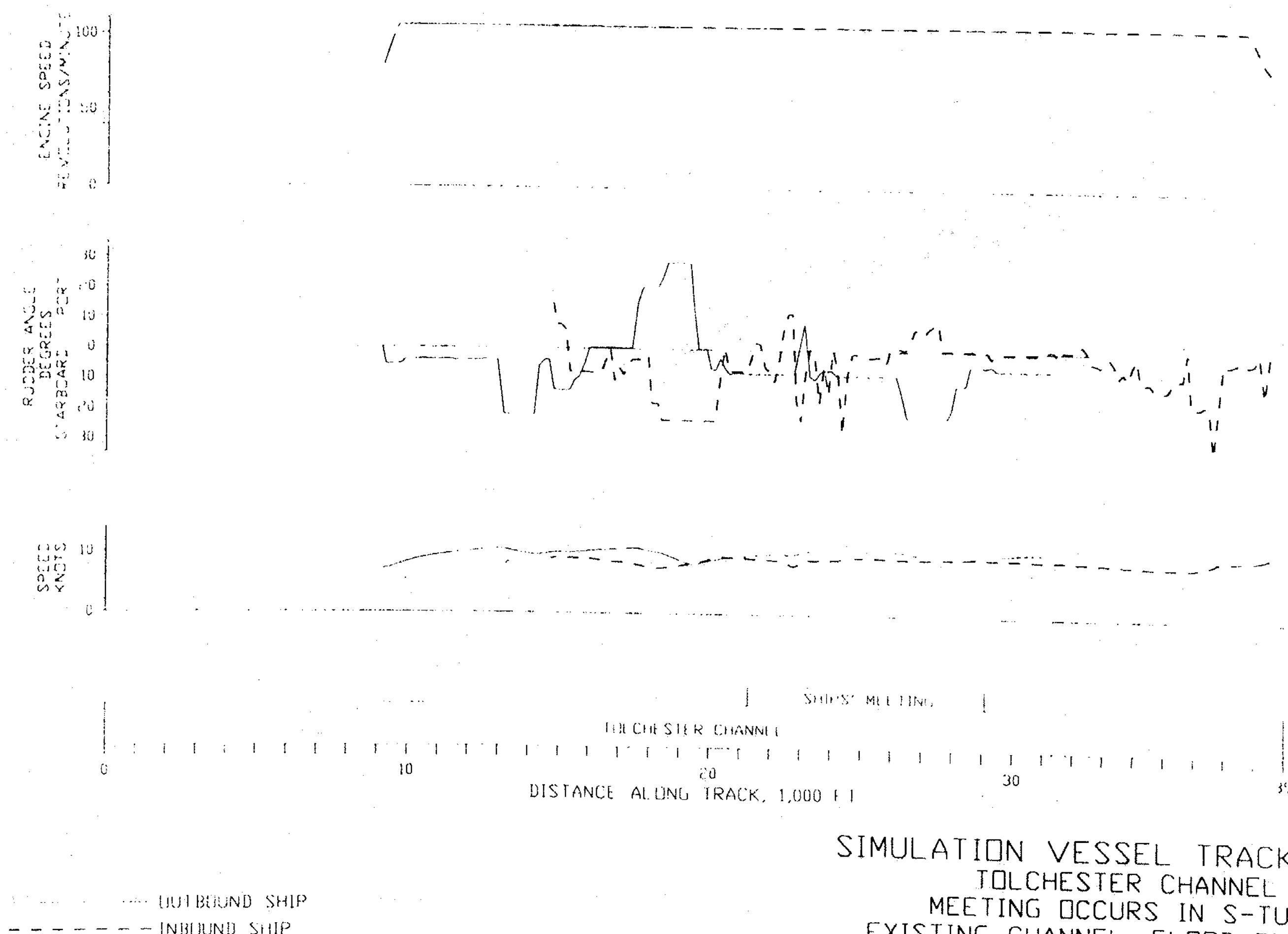
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 175

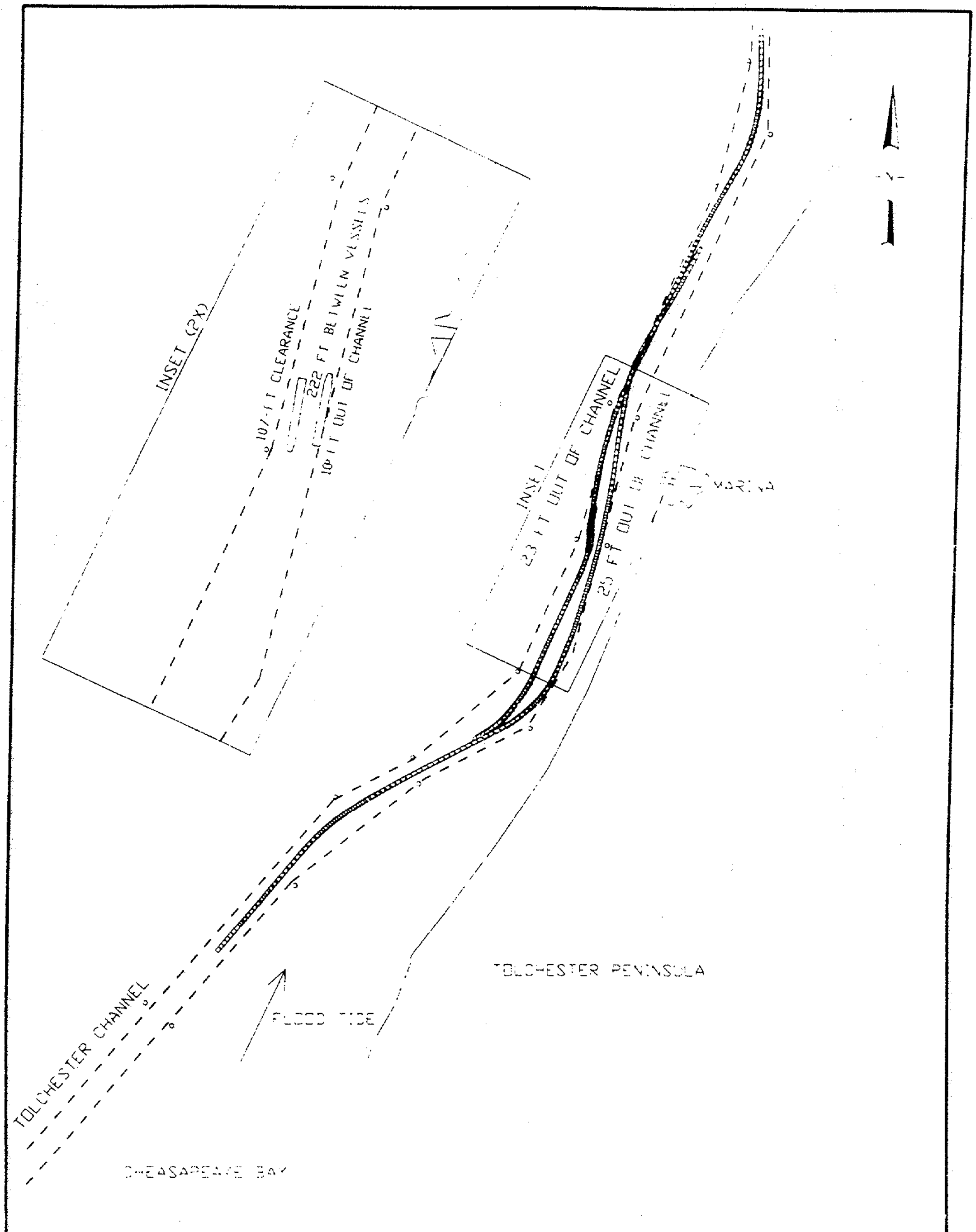
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

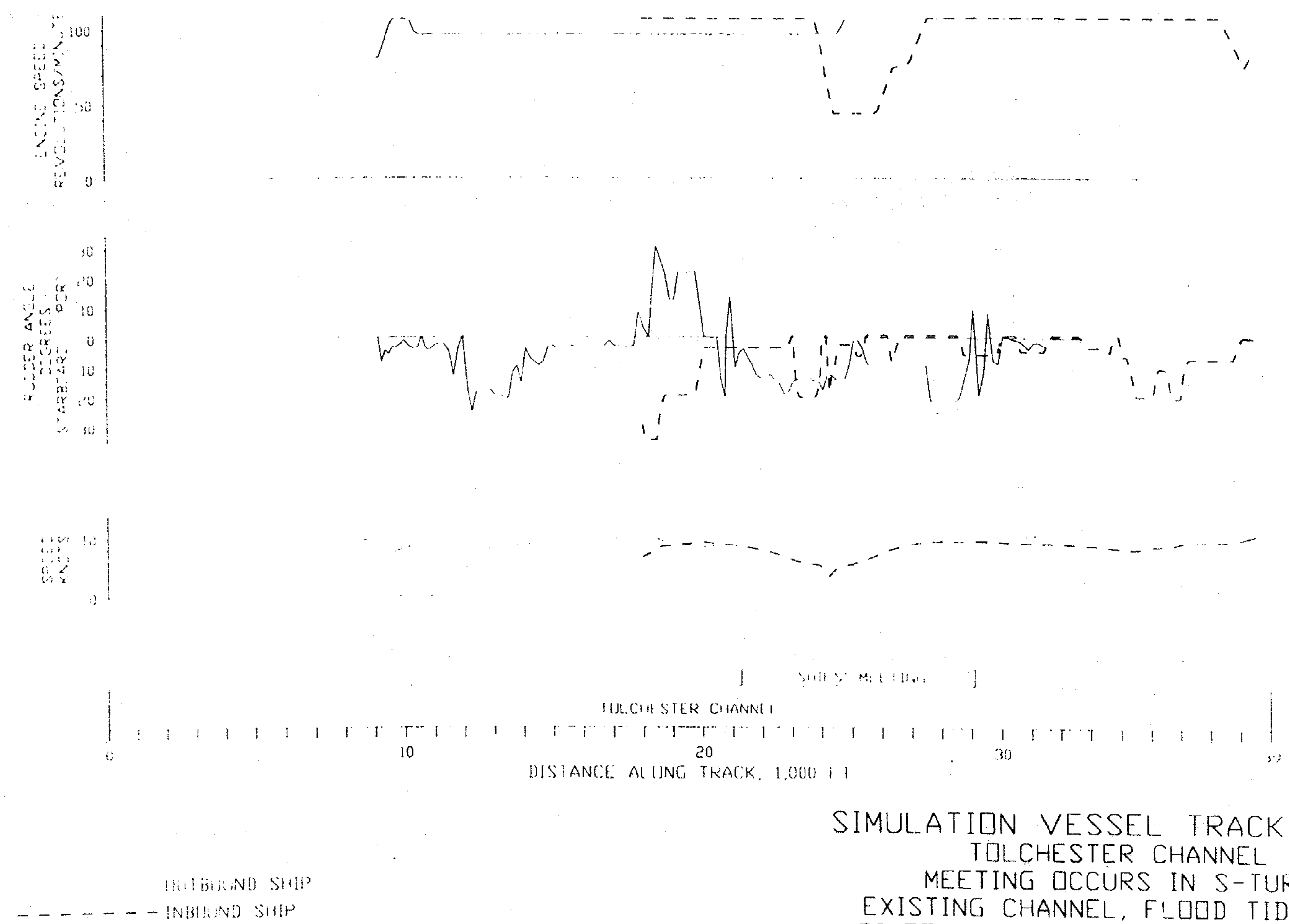
Plate 176

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

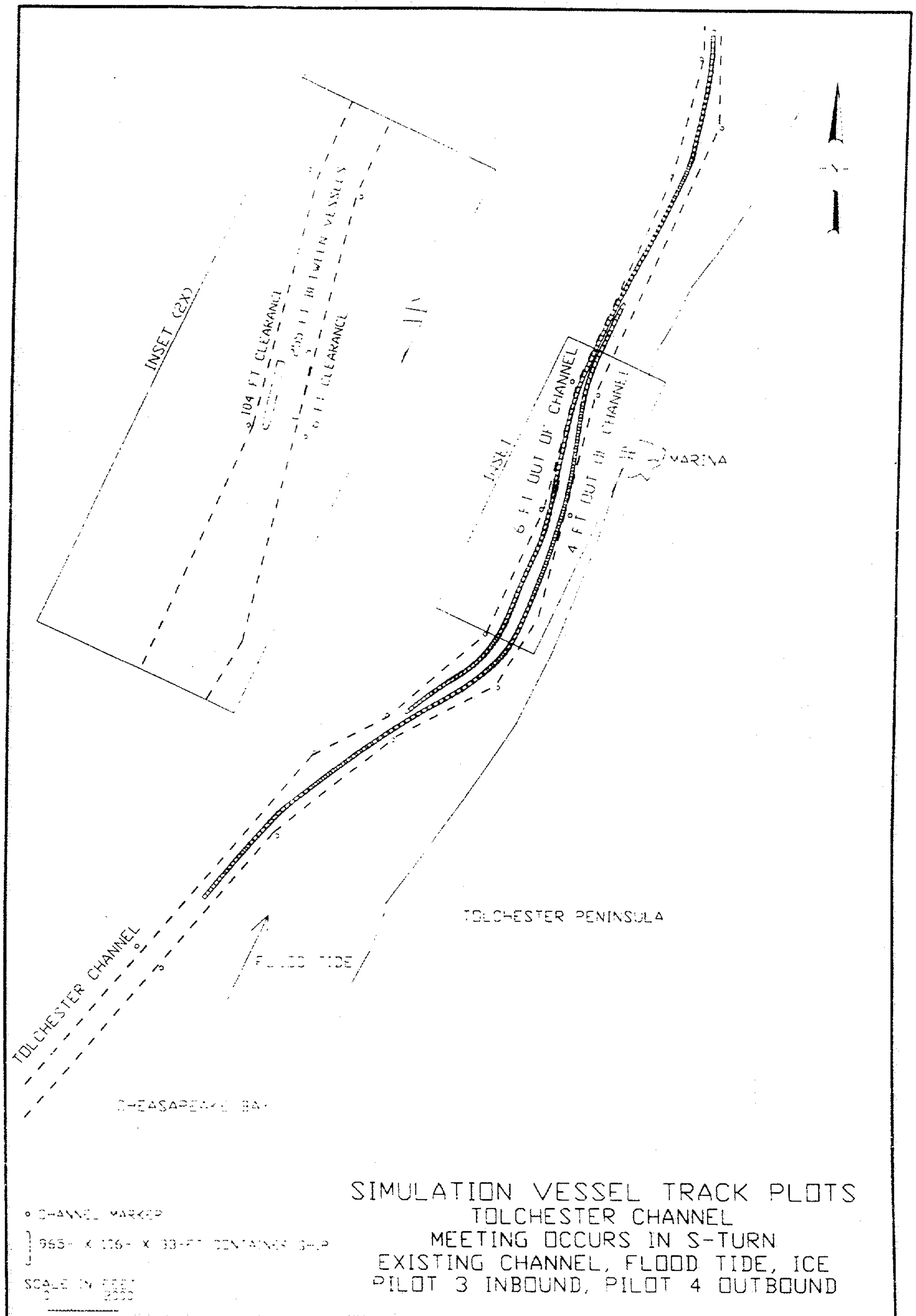
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 178

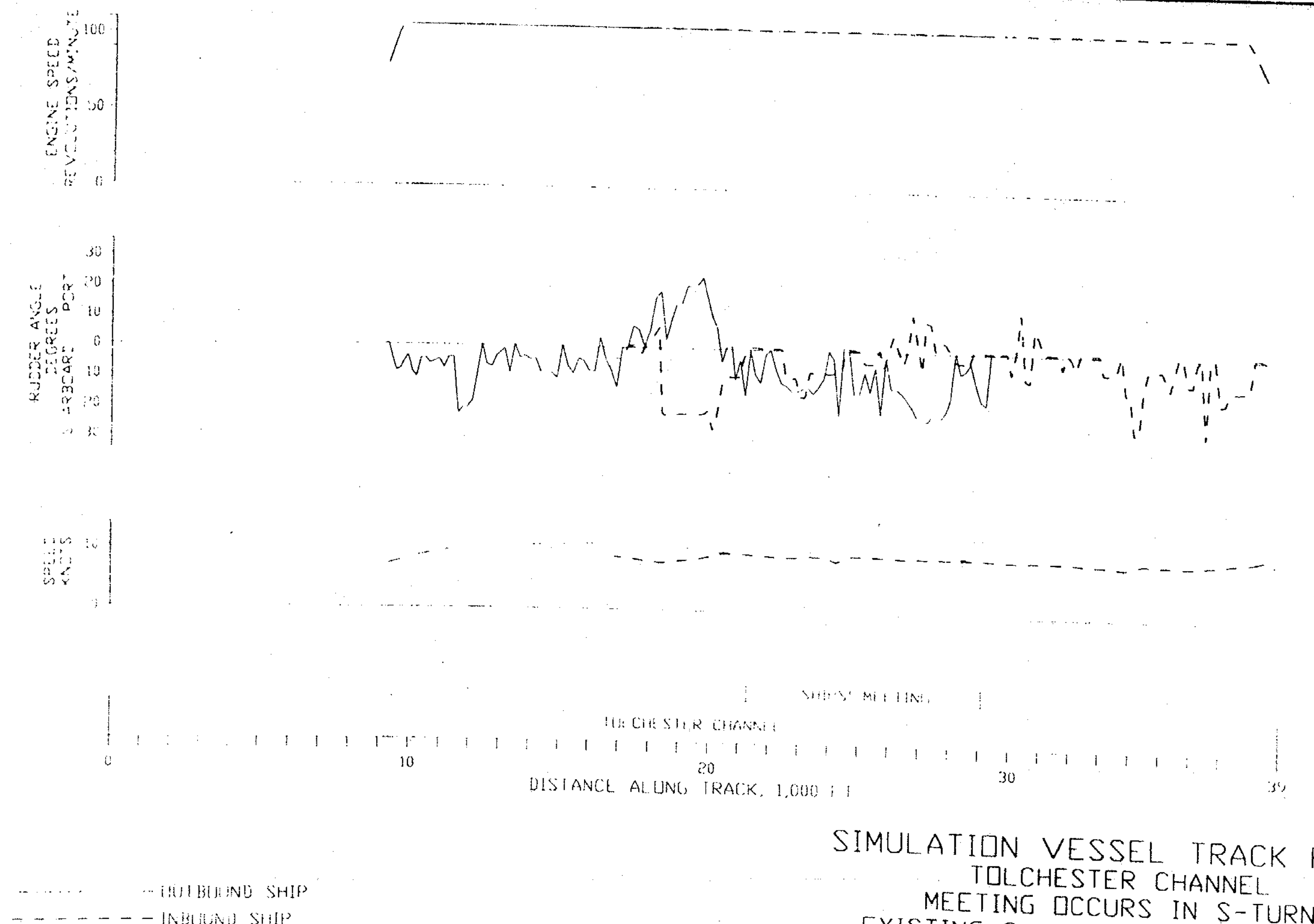
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

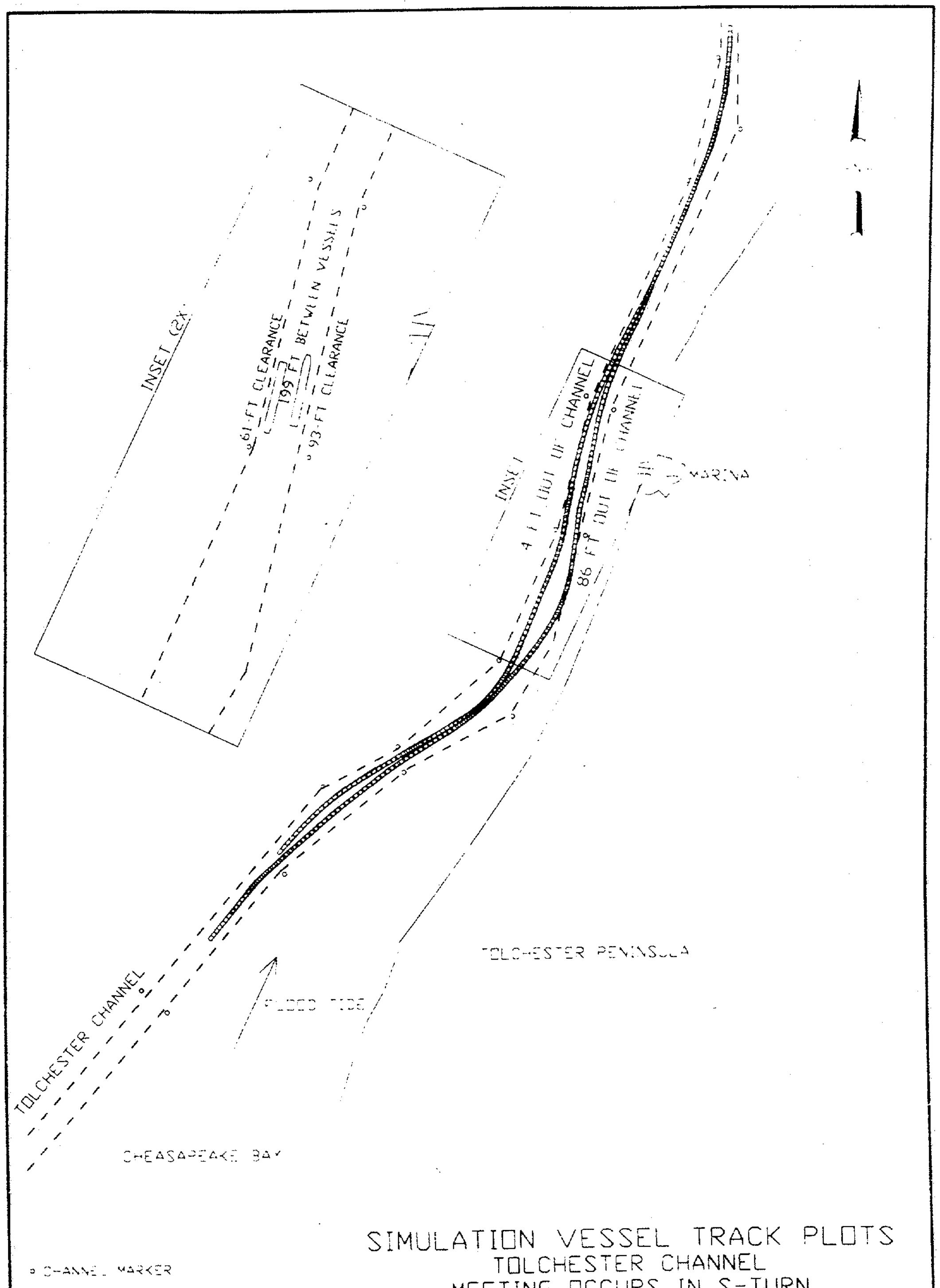
Plate 179

PRELIMINARY



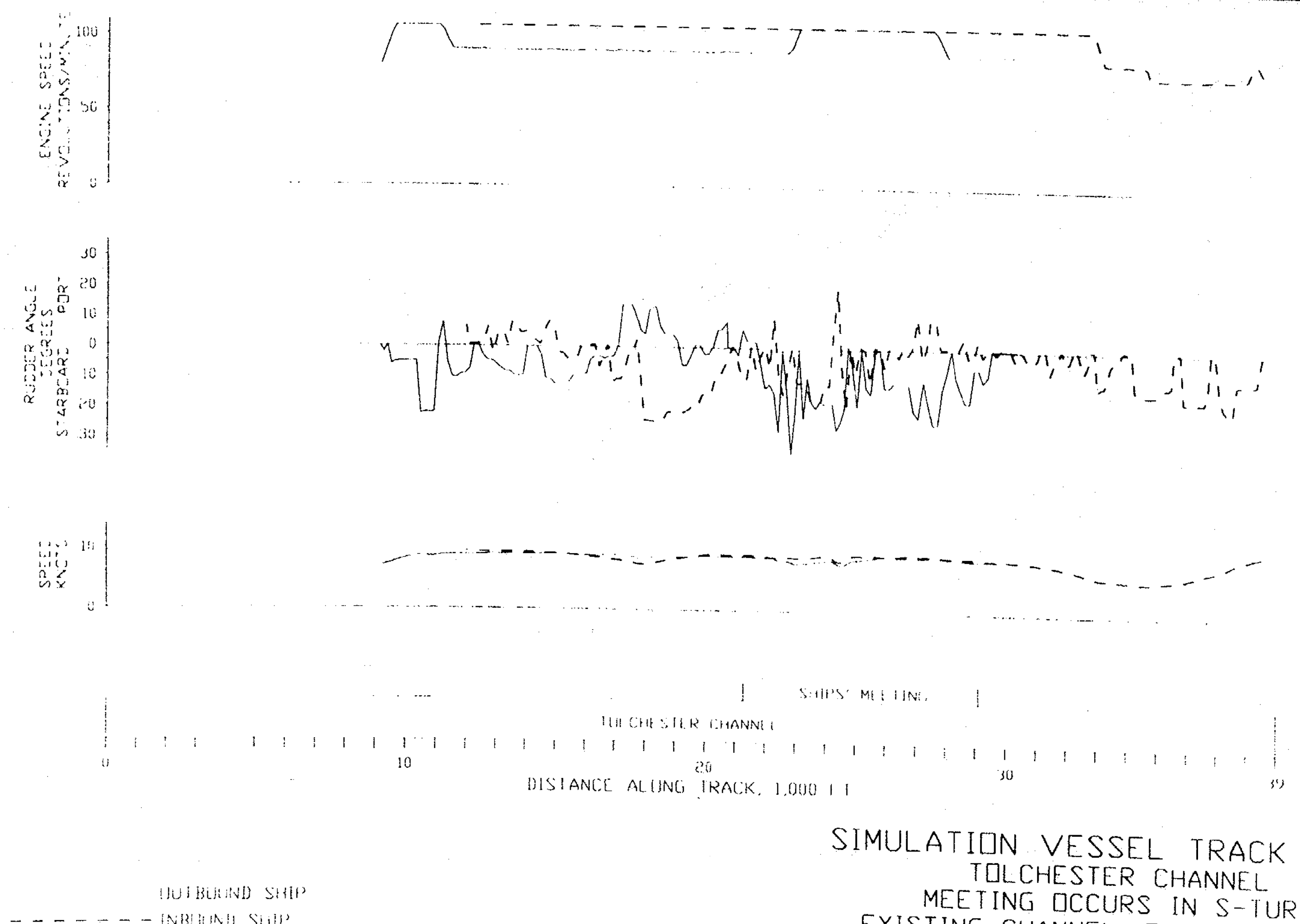
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

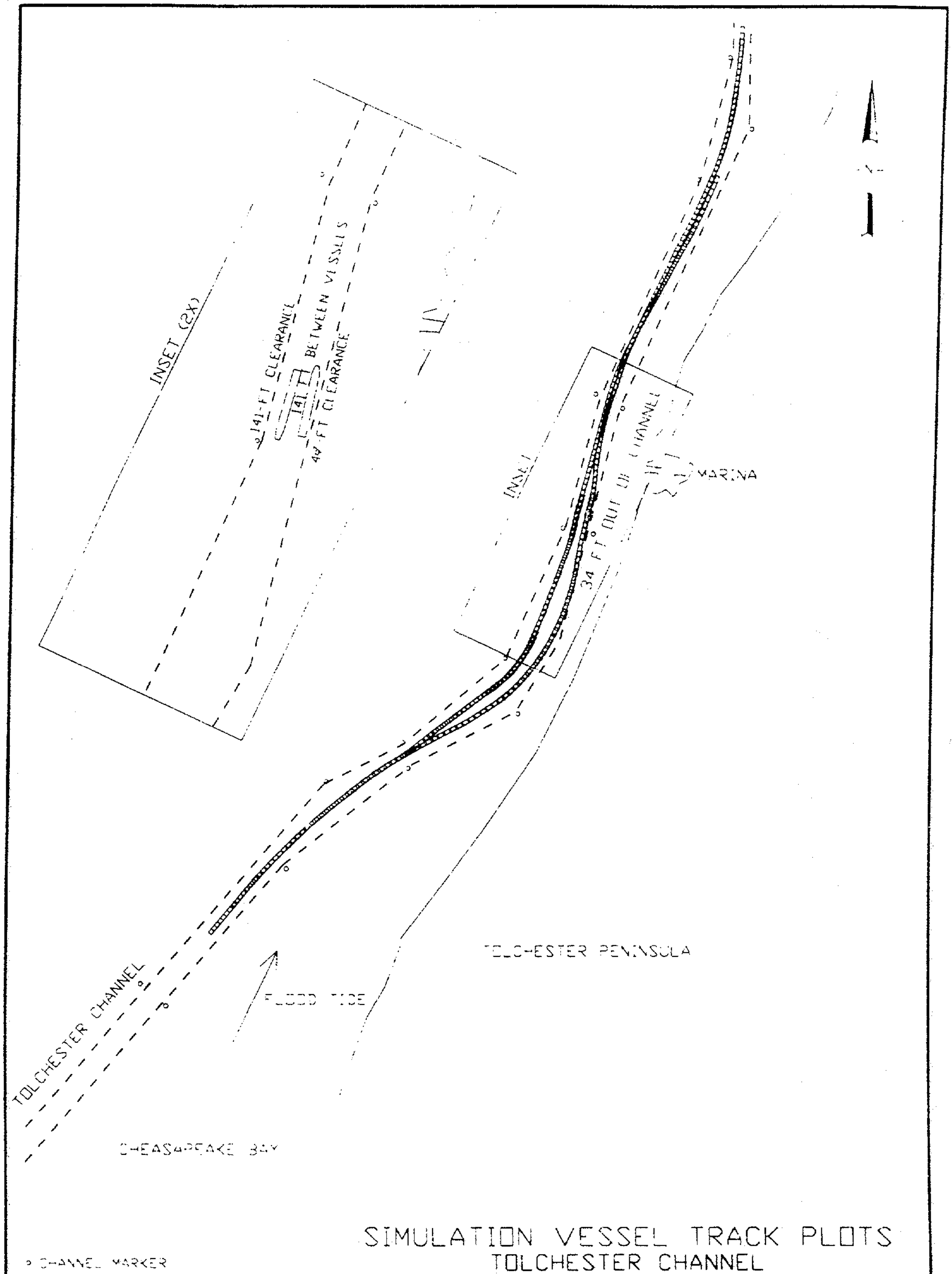
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

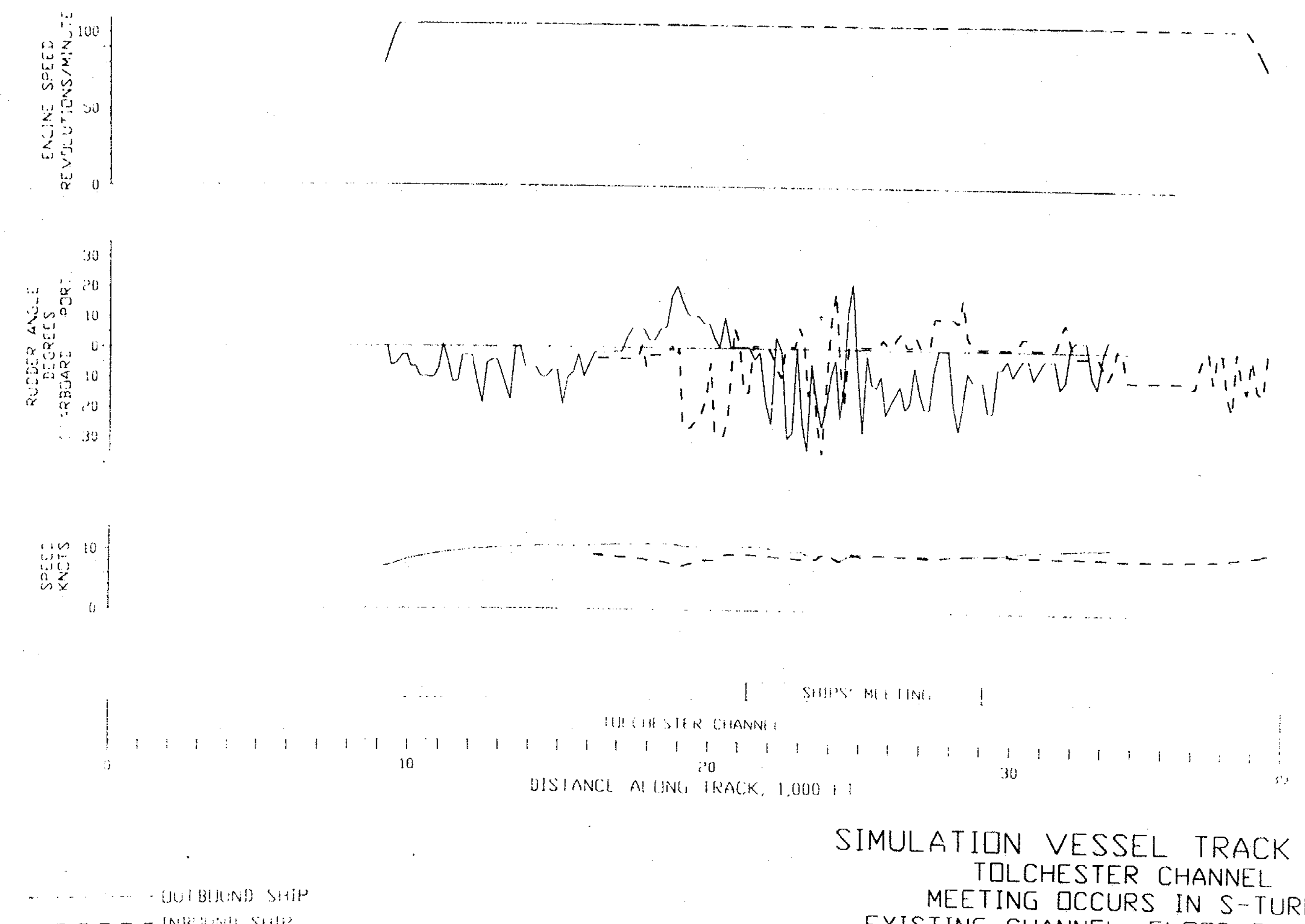
Plate 182

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

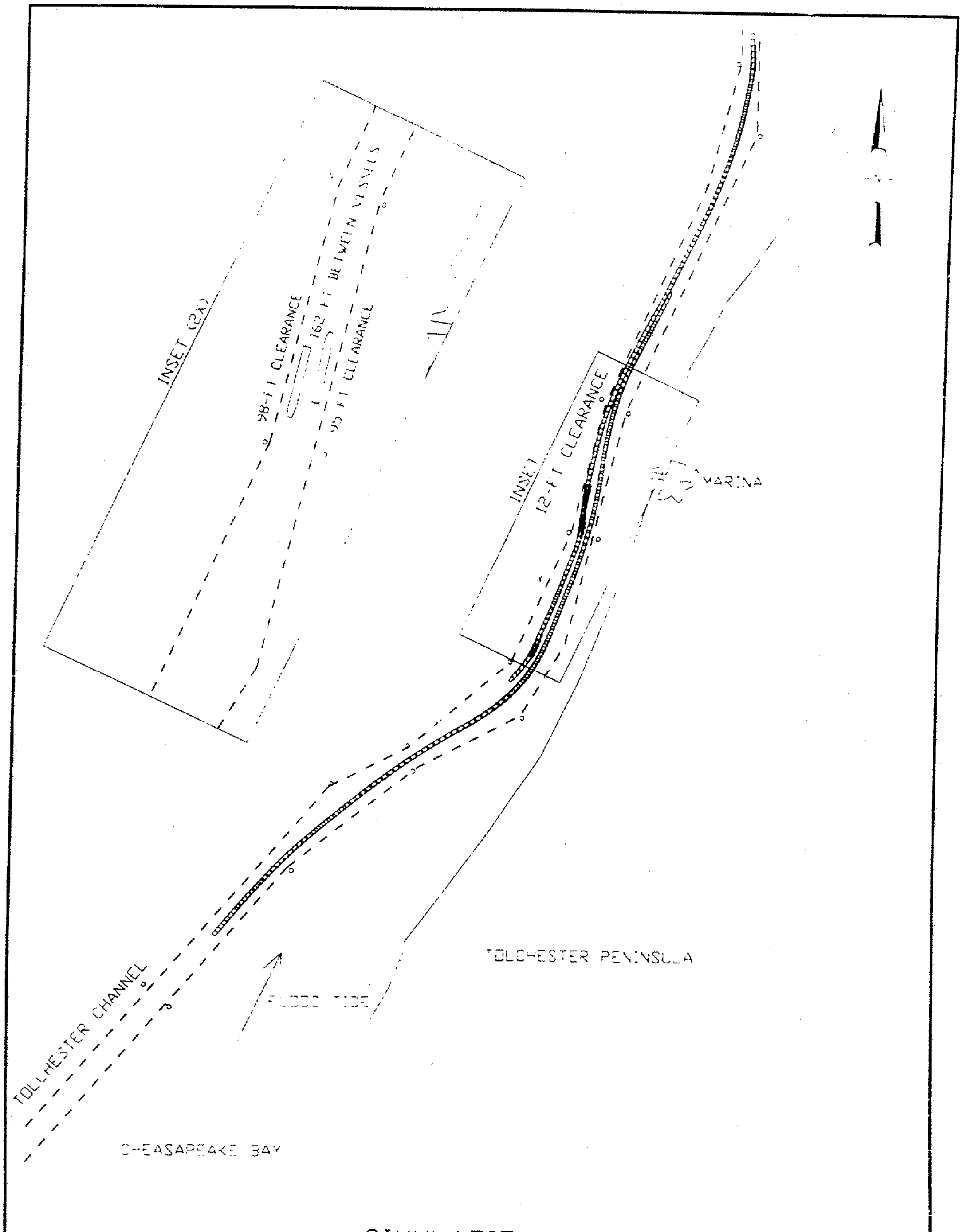
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 184

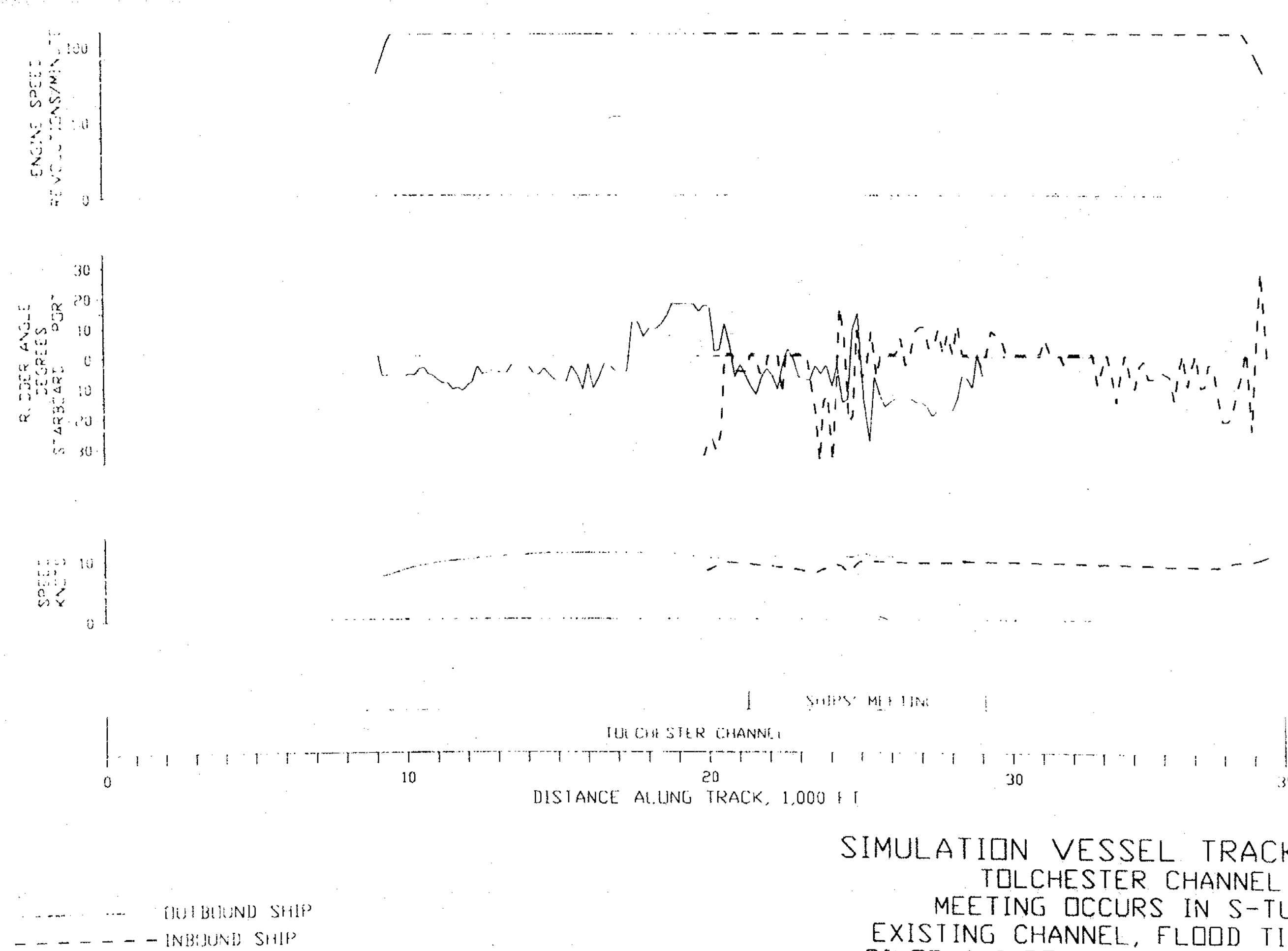
PRELIMINARY



CHANNEL MARKER
965- X 106- X 33-FT CONTAINER SHIP
SCALE IN FEET
0 2000

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

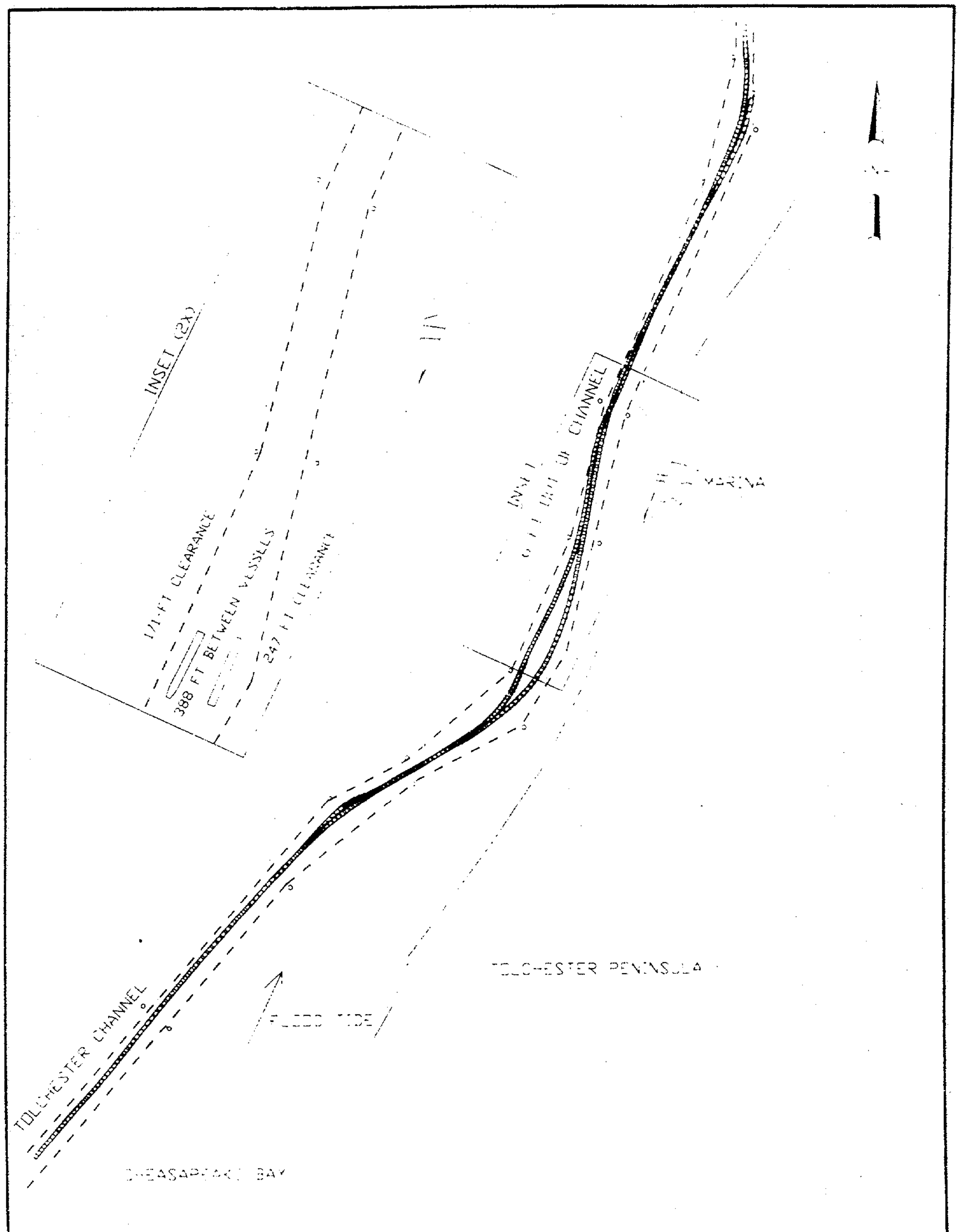
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN S-TURN
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

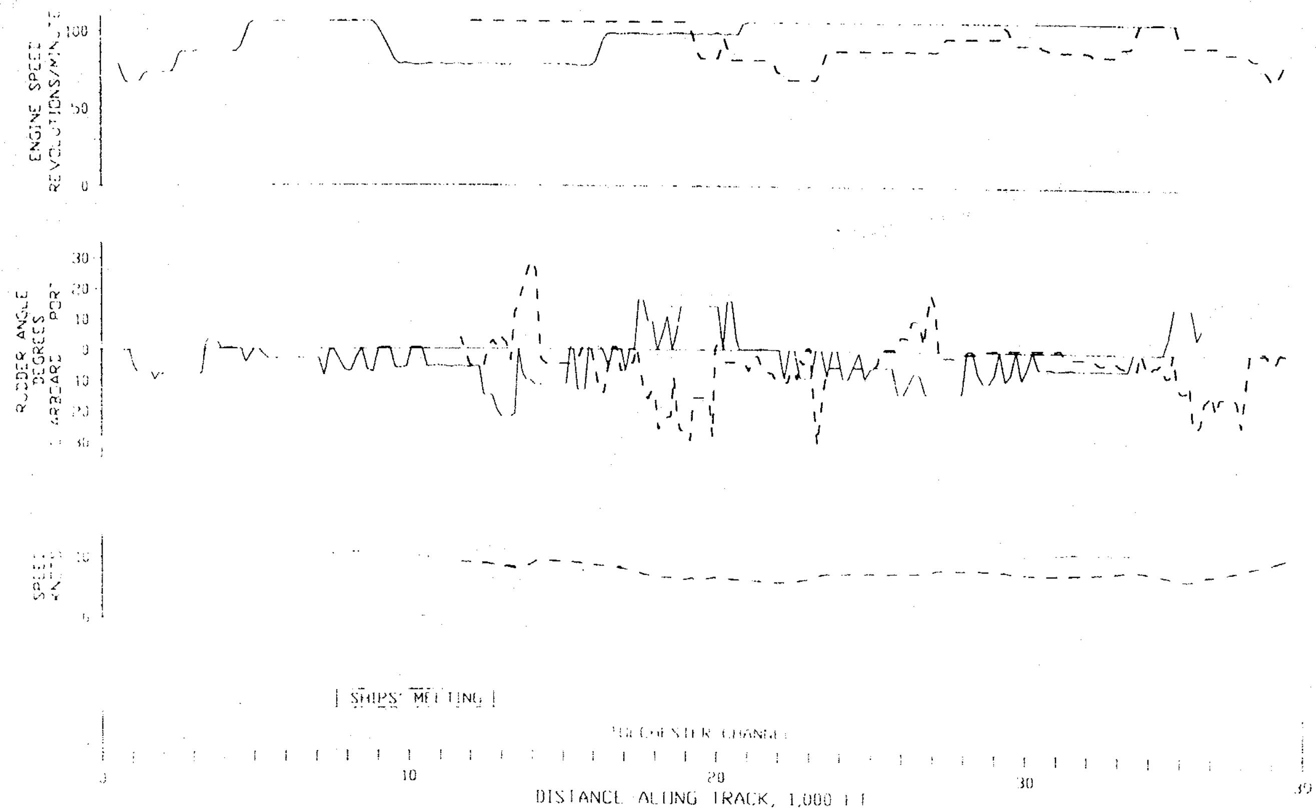
Plate 186

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

PRELIMINARY

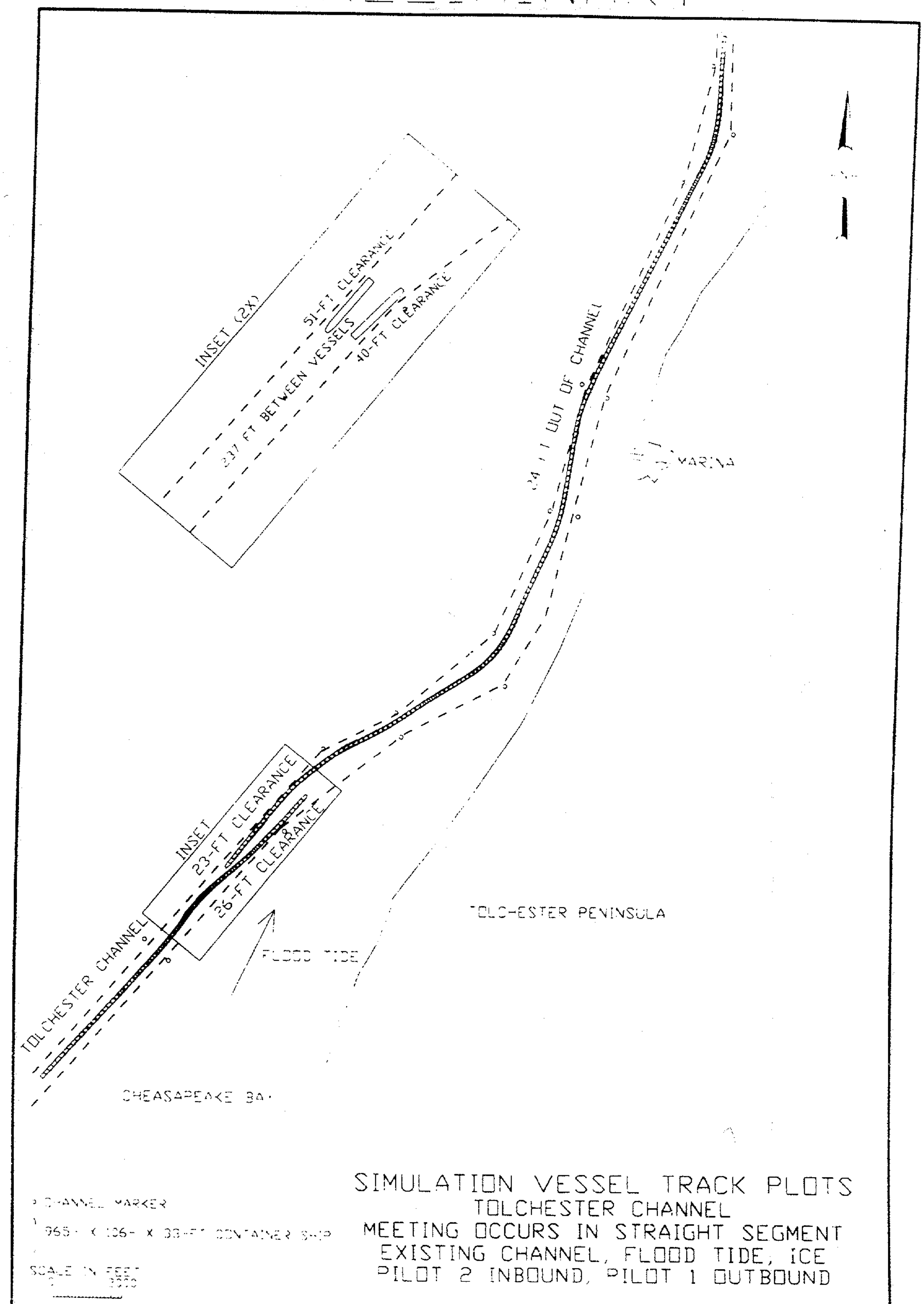


OUTBOUND SHIP
- - - - - - - INBOUND SHIP

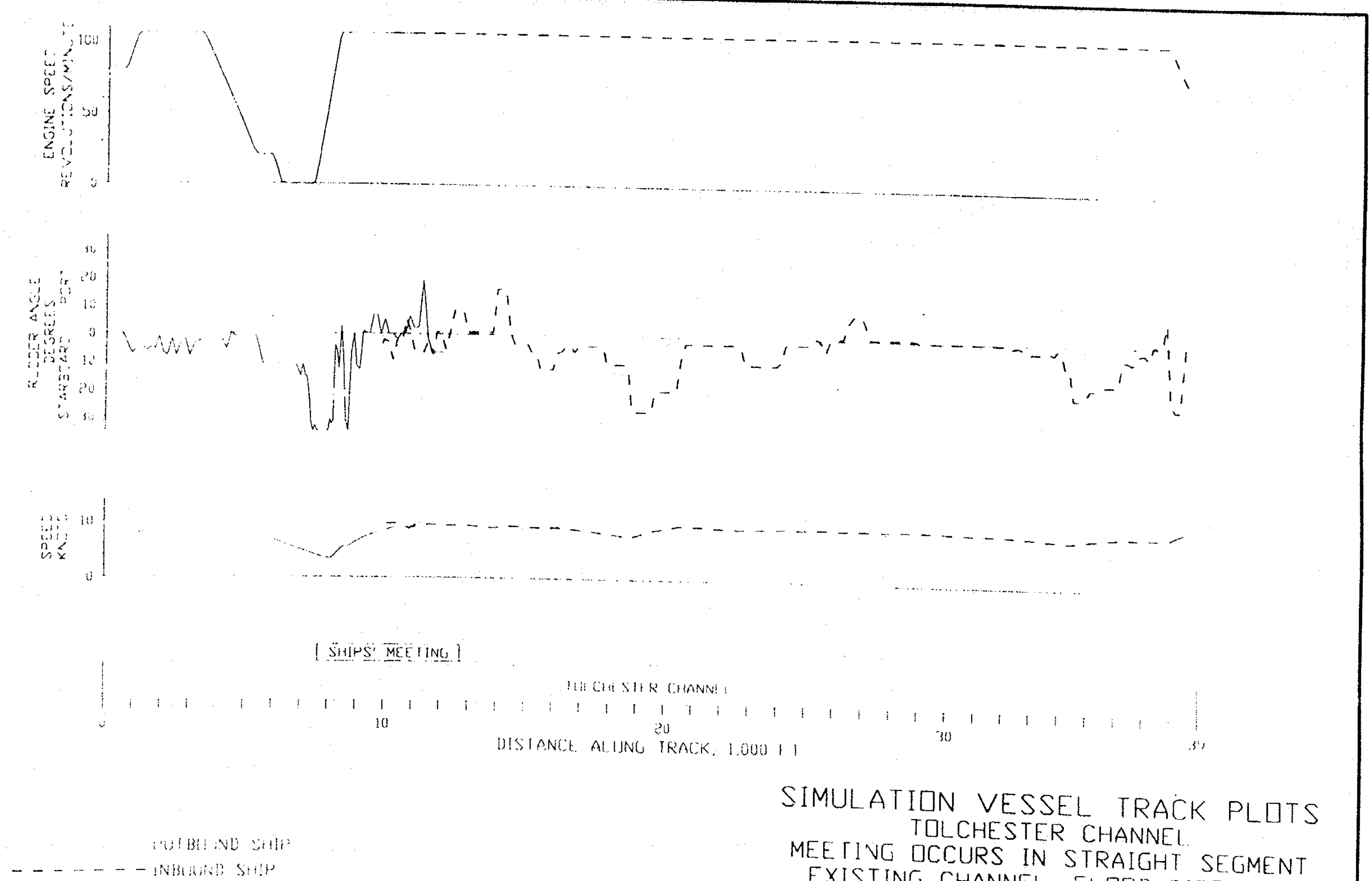
SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 188

PRELIMINARY



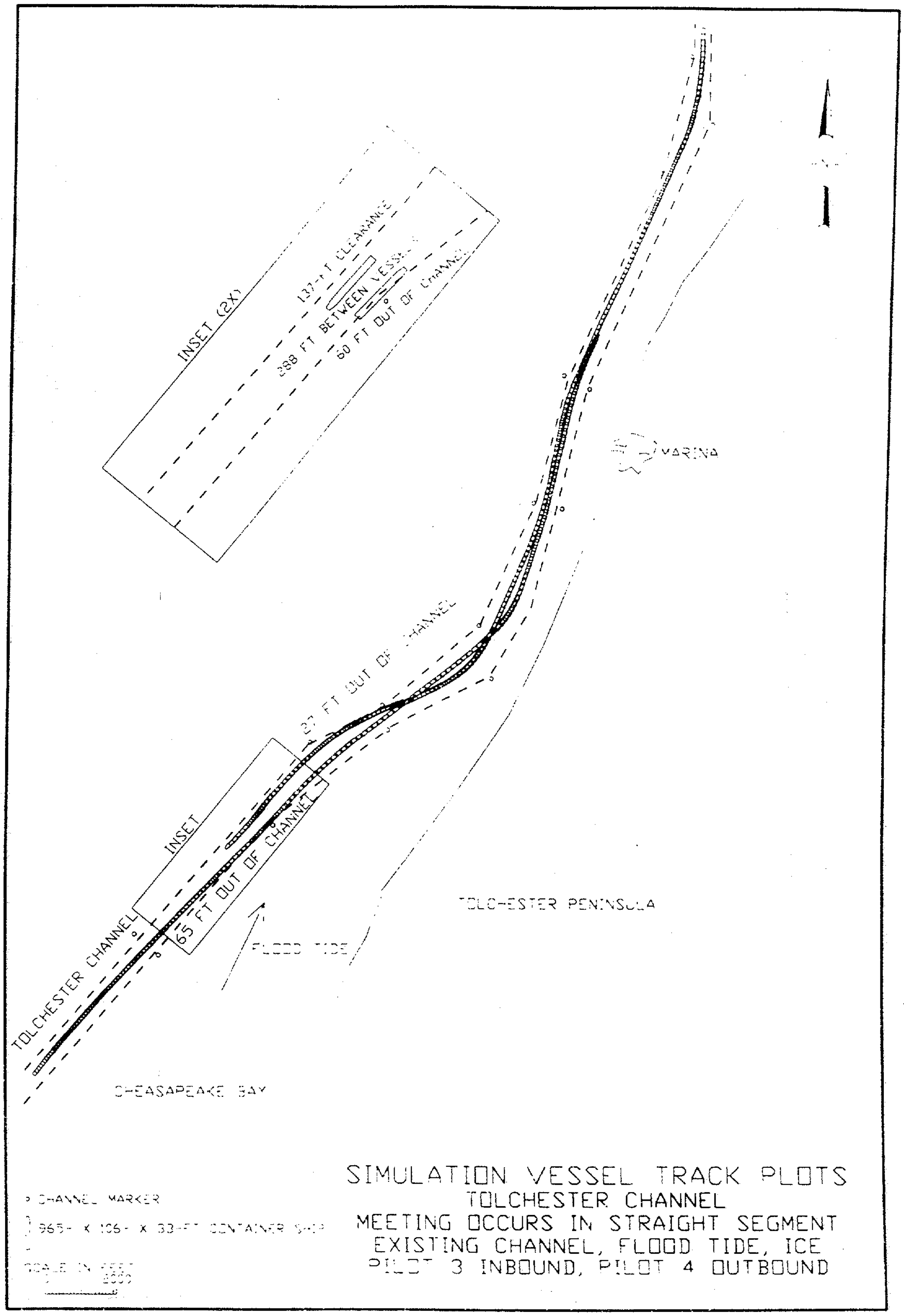
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 190

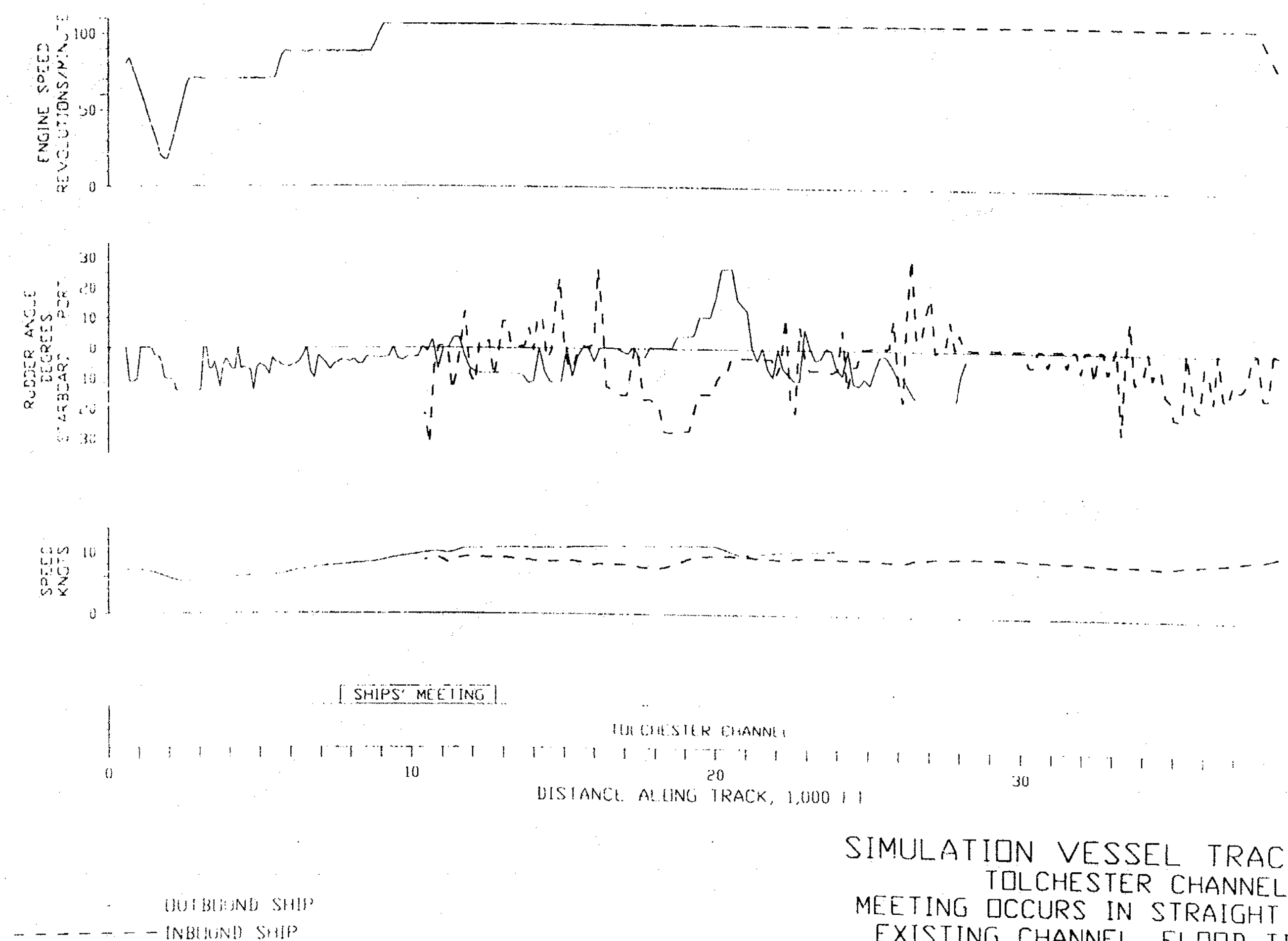
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

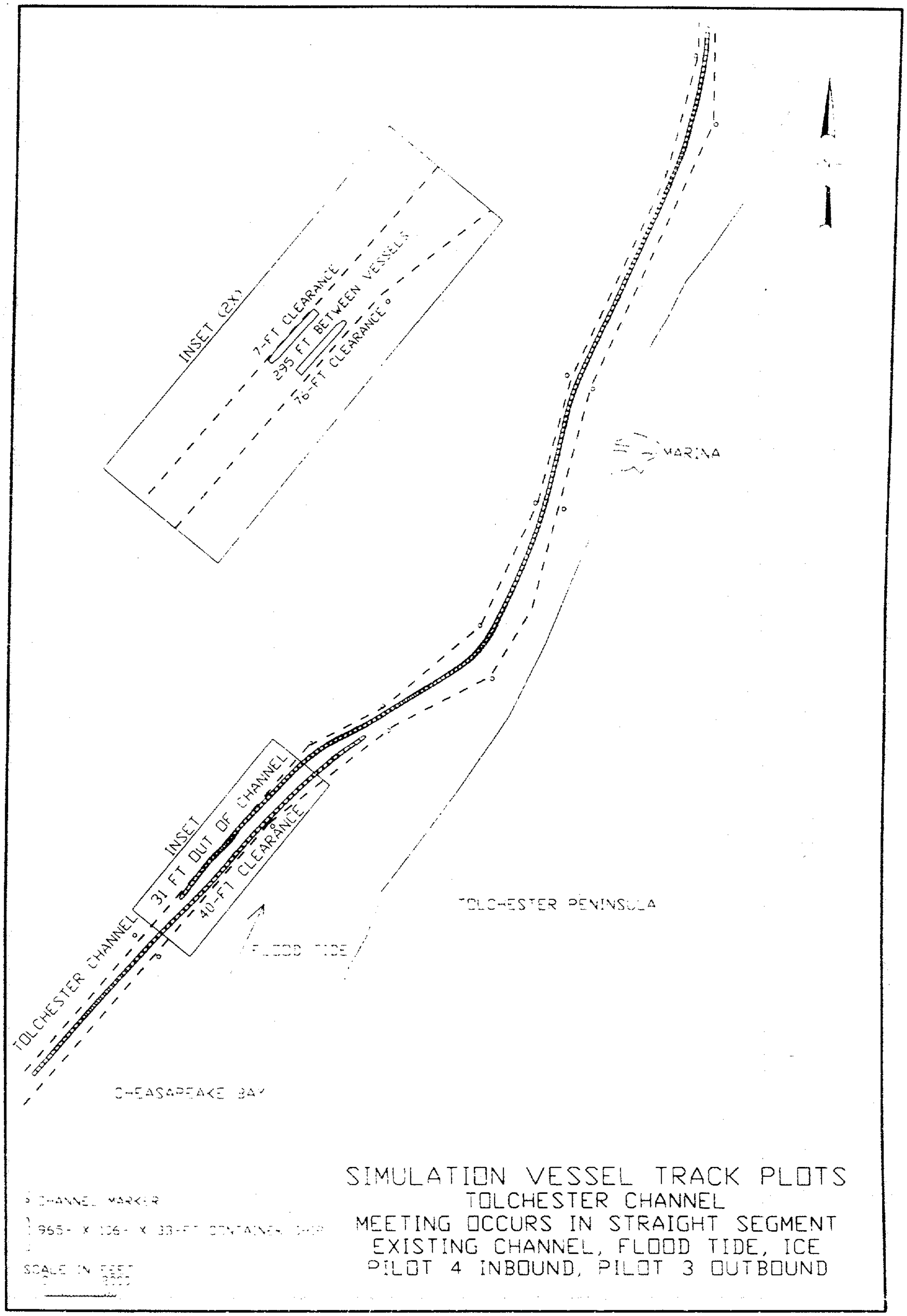
Plate 191

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

PRELIMINARY

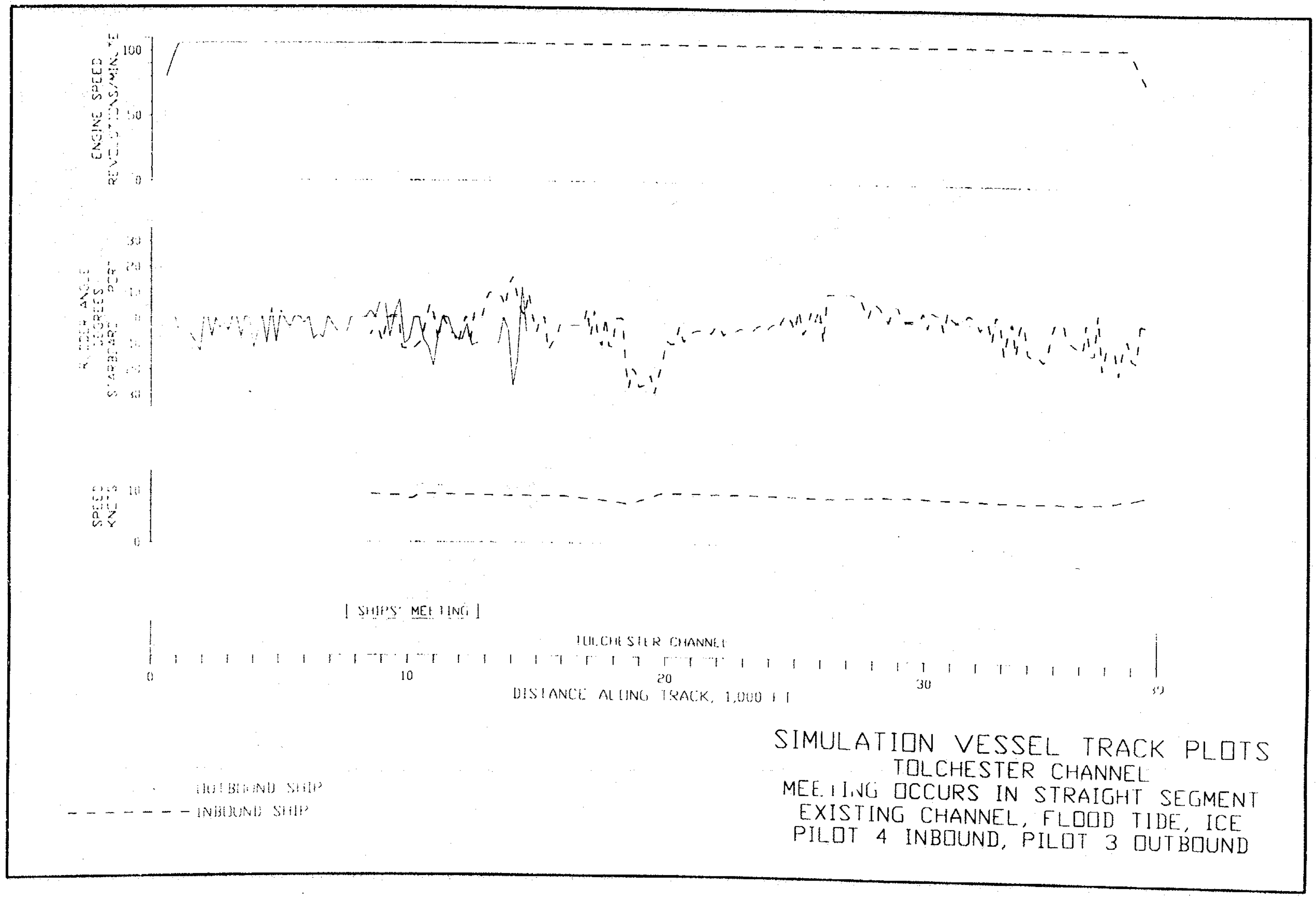
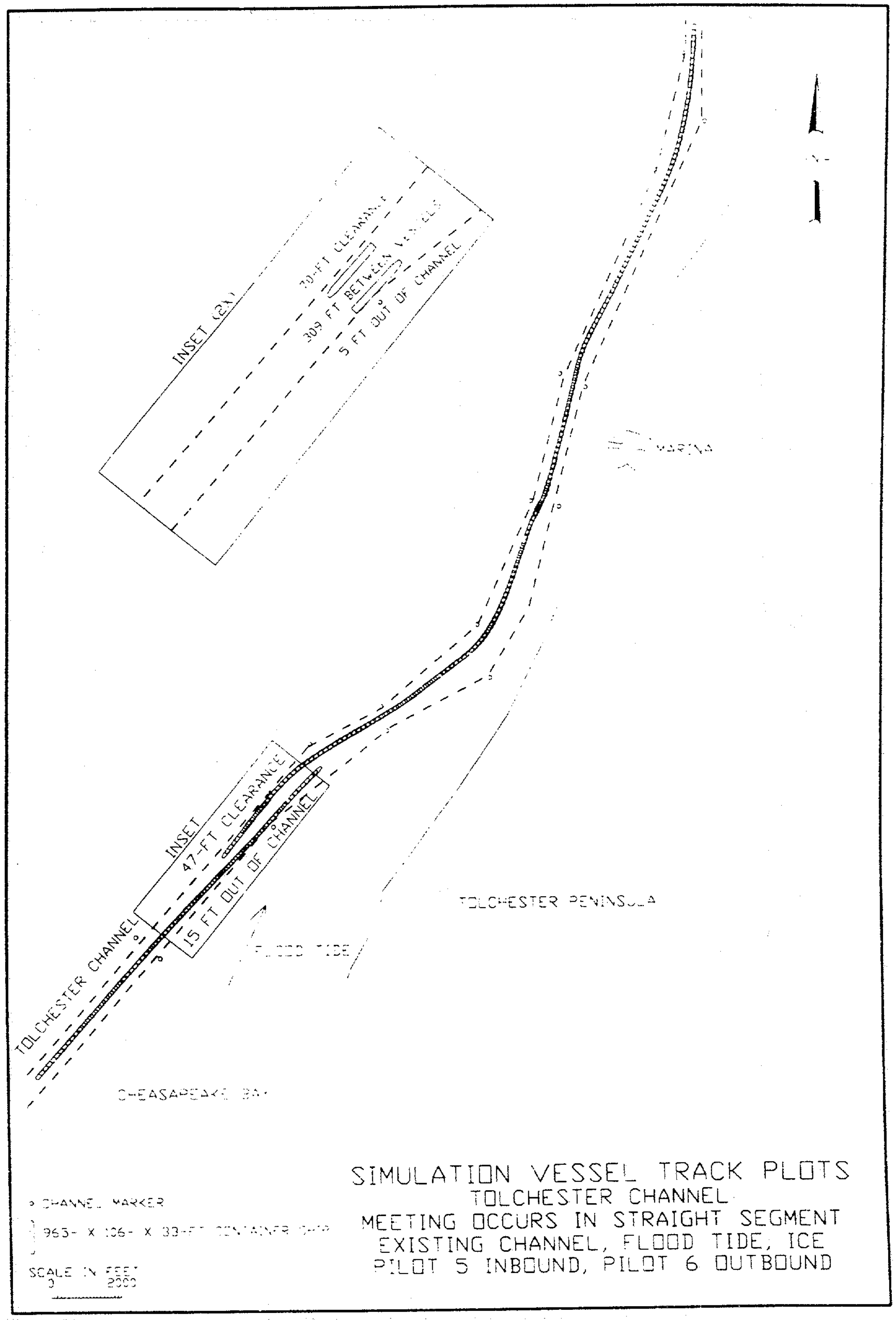
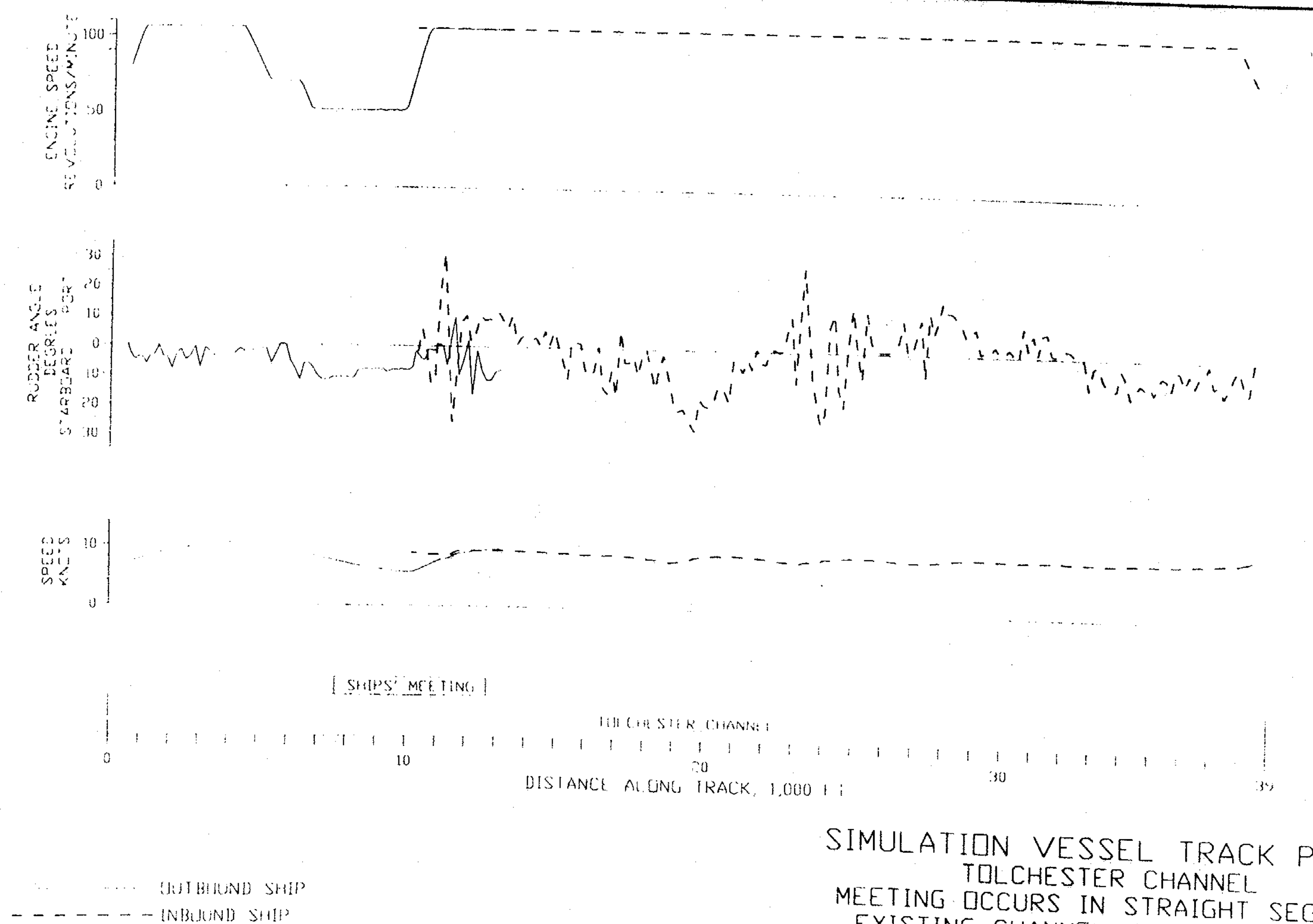


Plate 194

PRELIMINARY



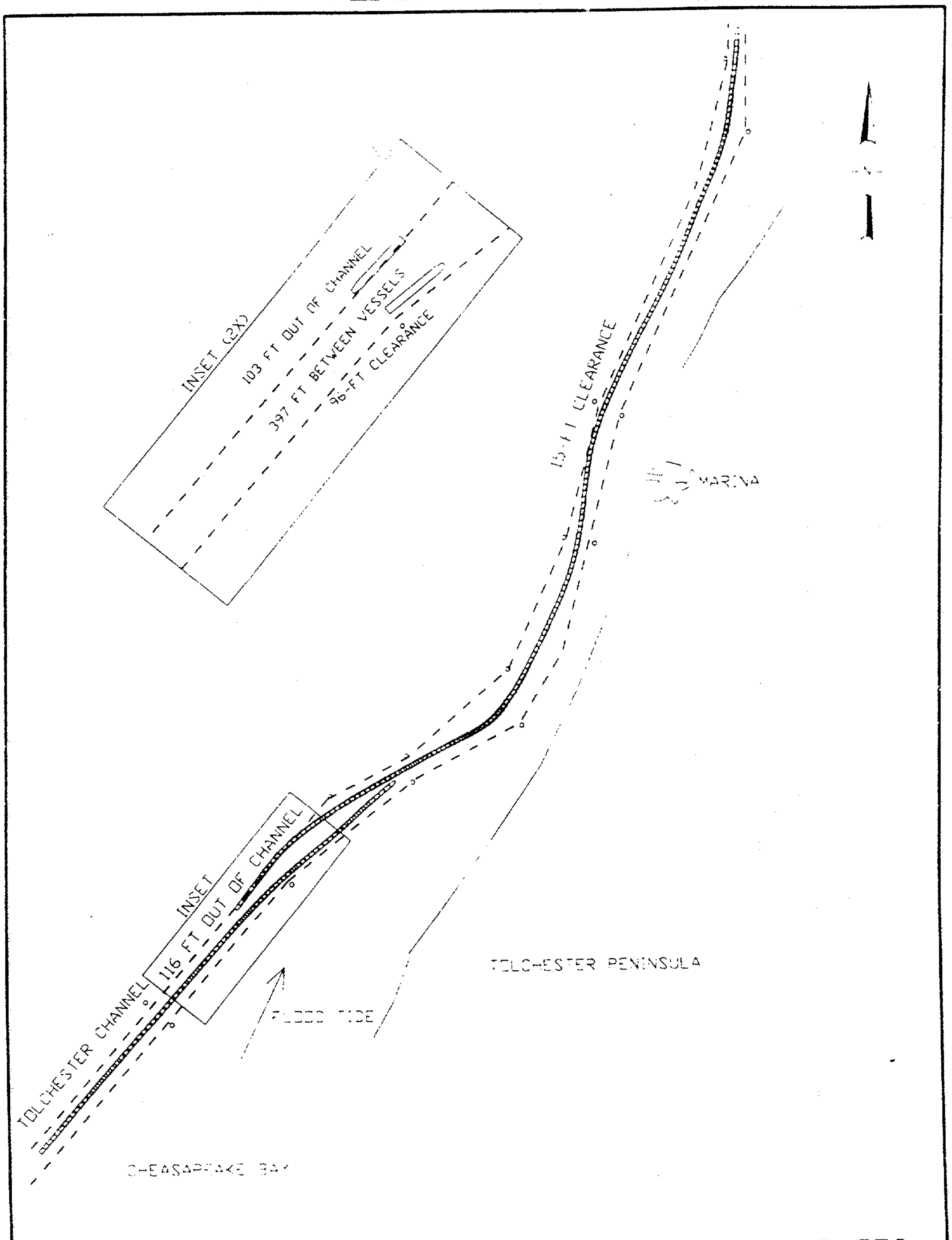
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 196

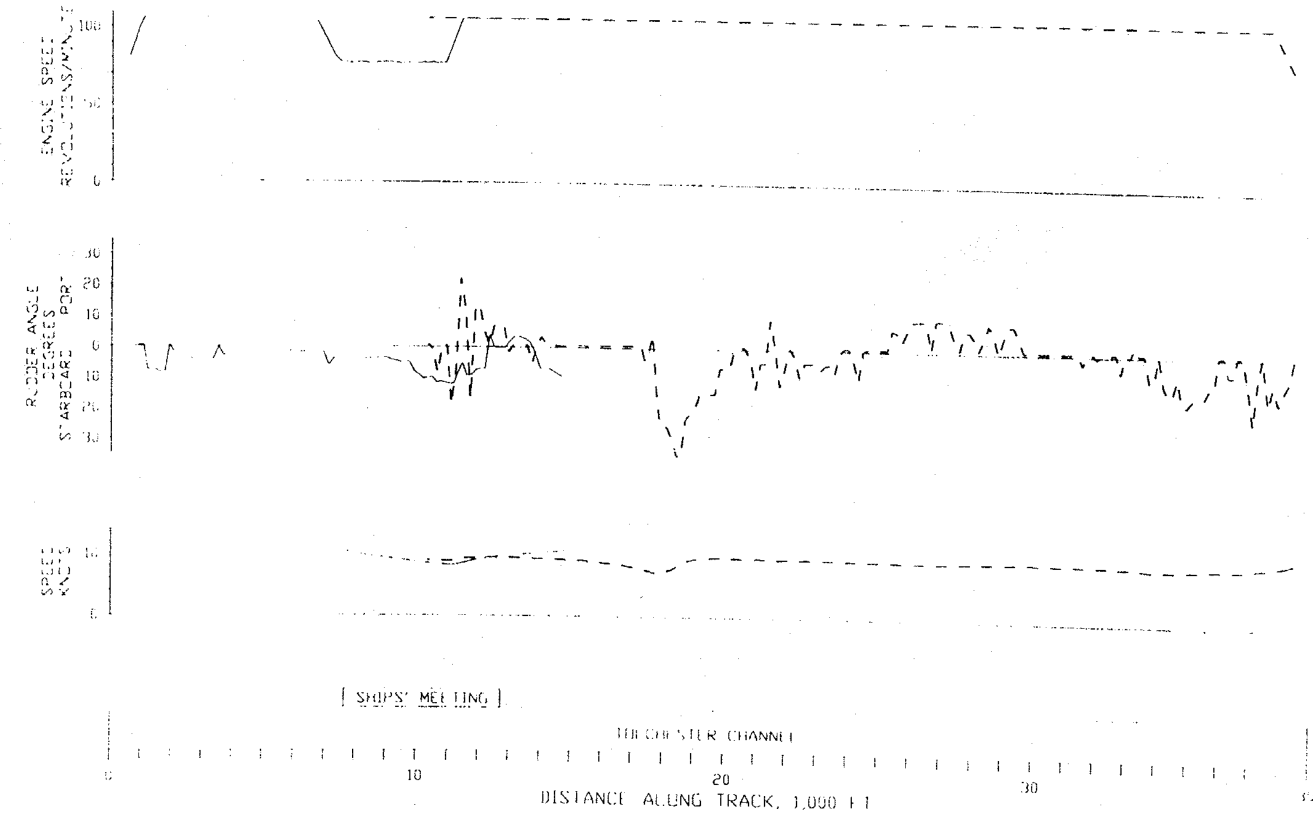
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 197

PRELIMINARY

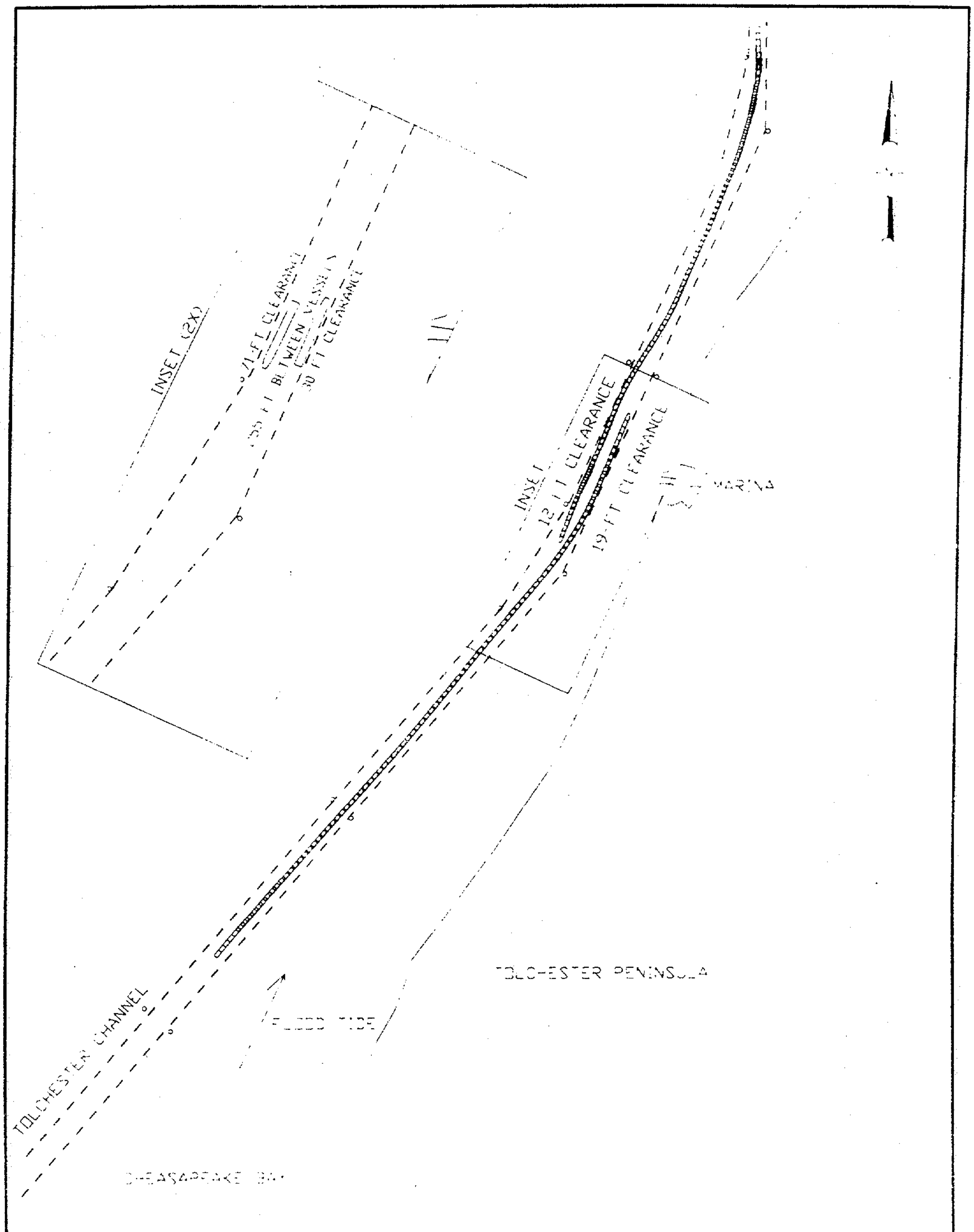


OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
MEETING OCCURS IN STRAIGHT SEGMENT
EXISTING CHANNEL, FLOOD TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

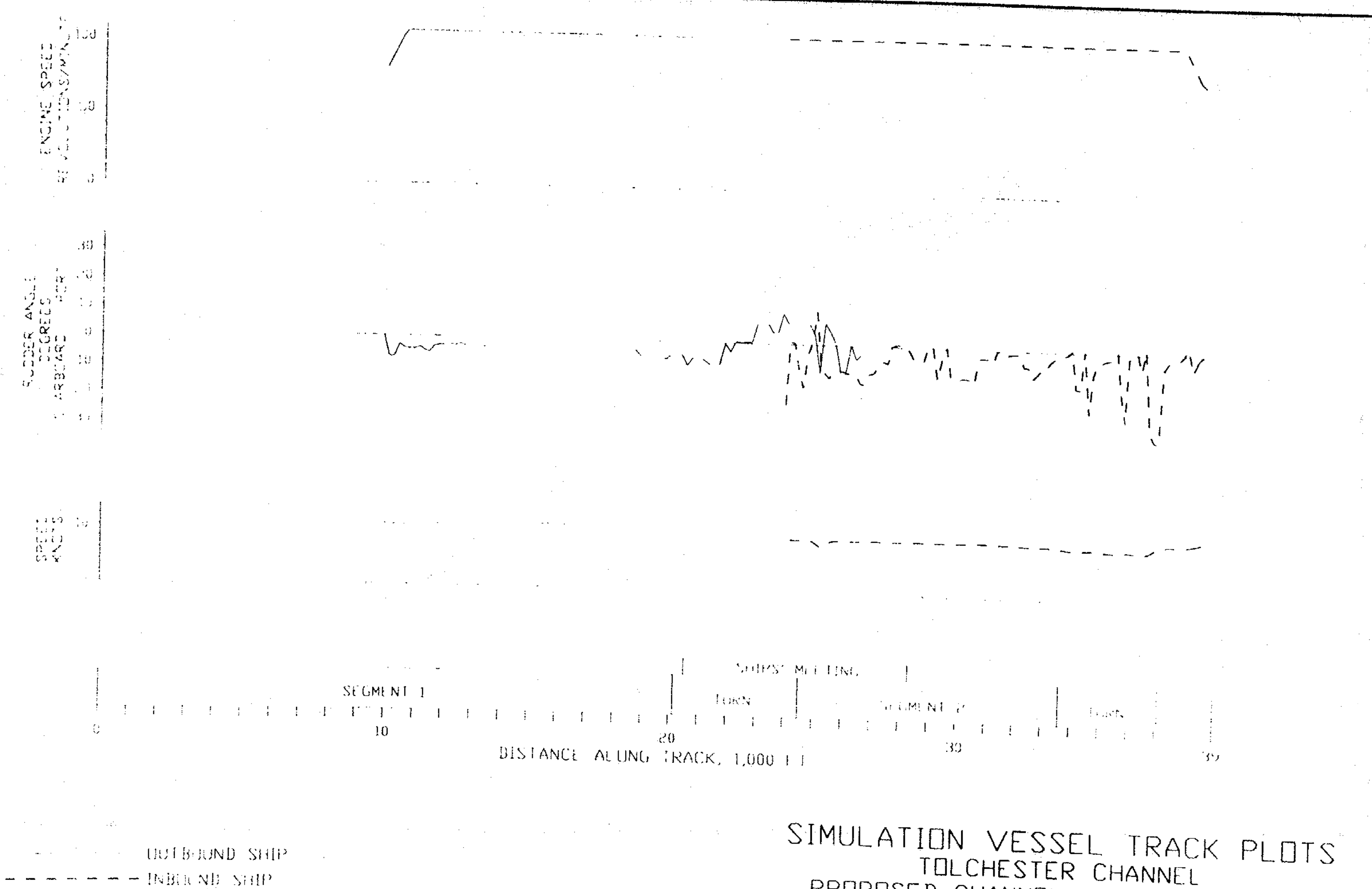
Plate 198

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

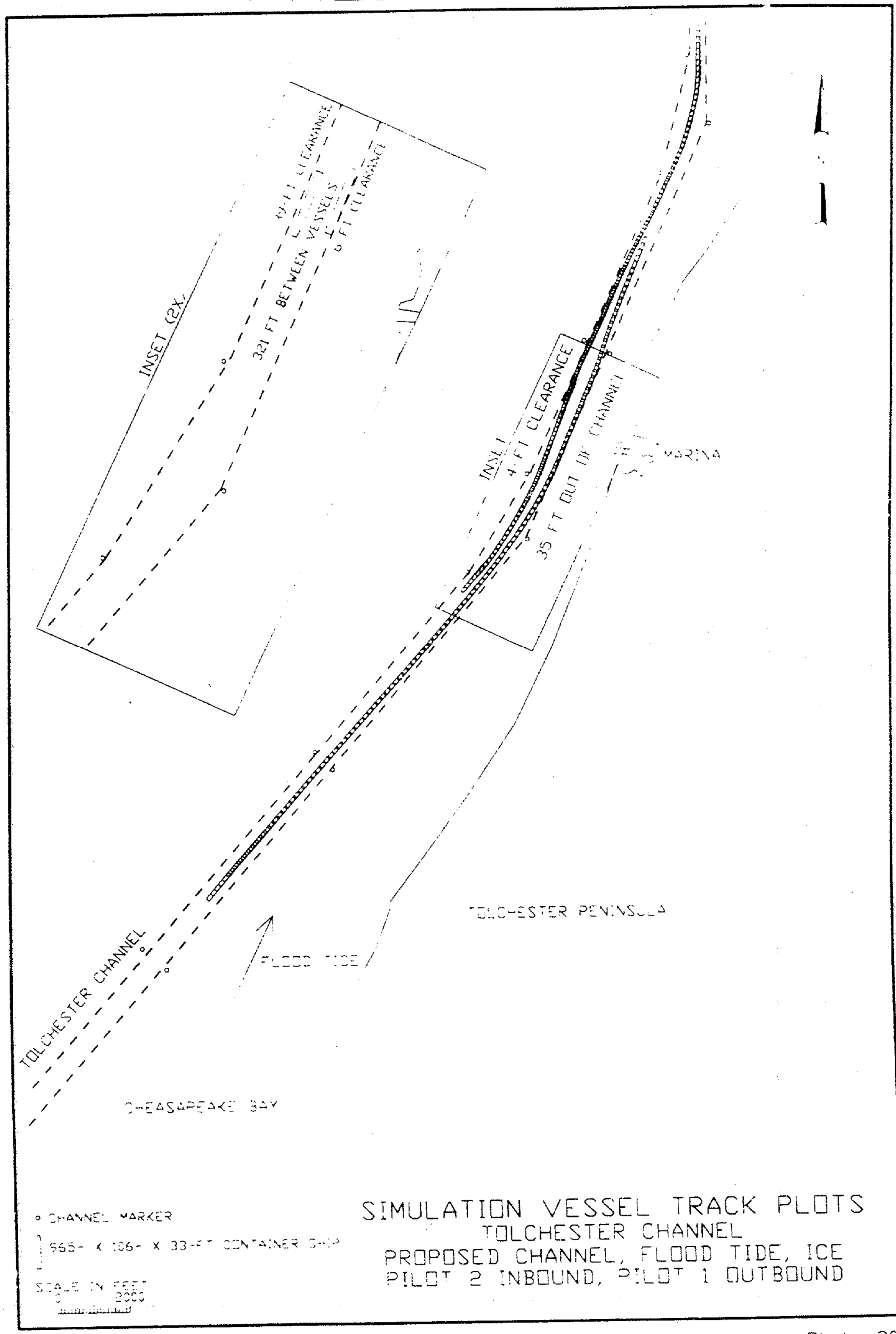
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 1 INBOUND, PILOT 2 OUTBOUND

Plate 200

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 2 INBOUND, PILOT 1 OUTBOUND

Plate 201

PRELIMINARY

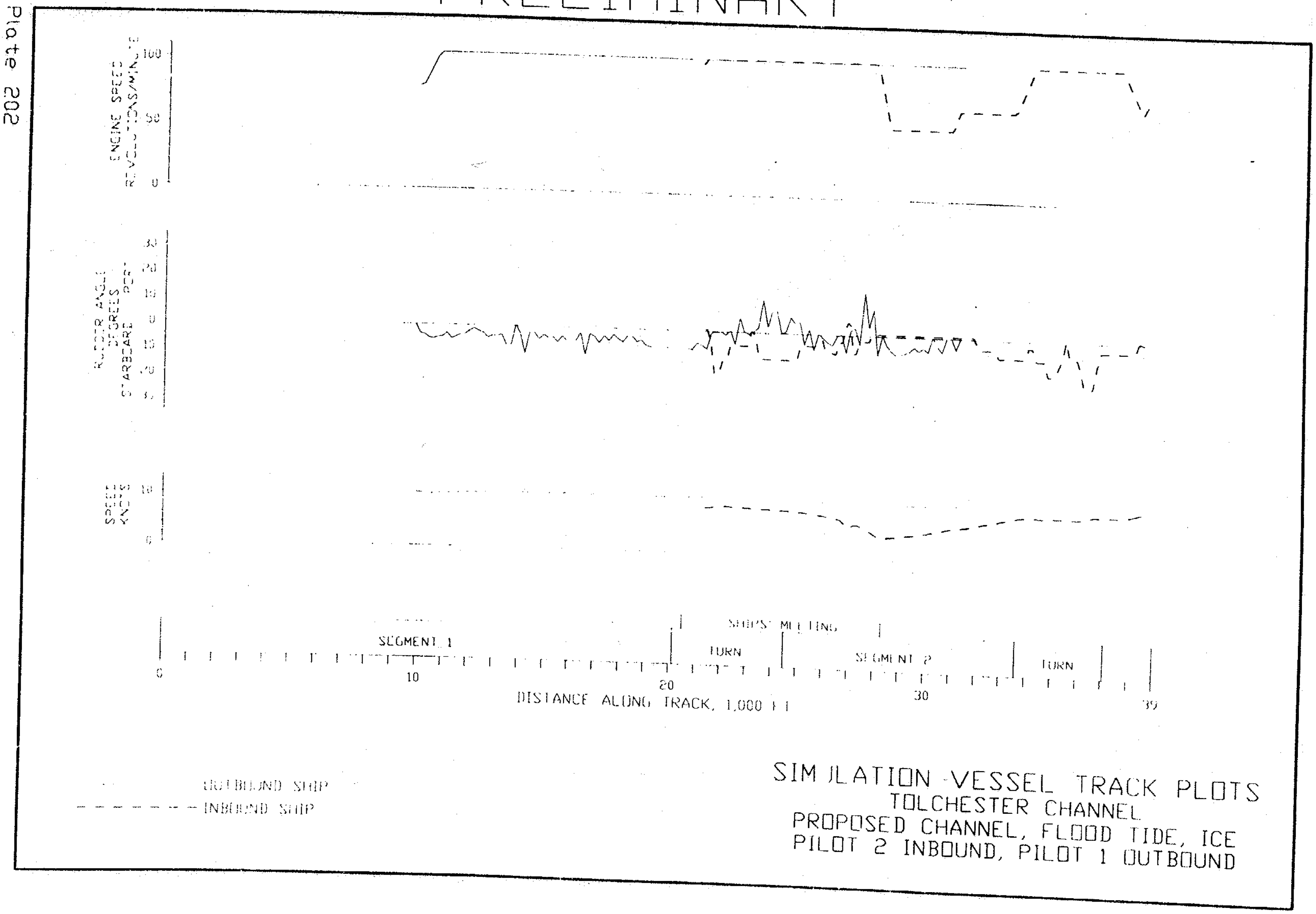
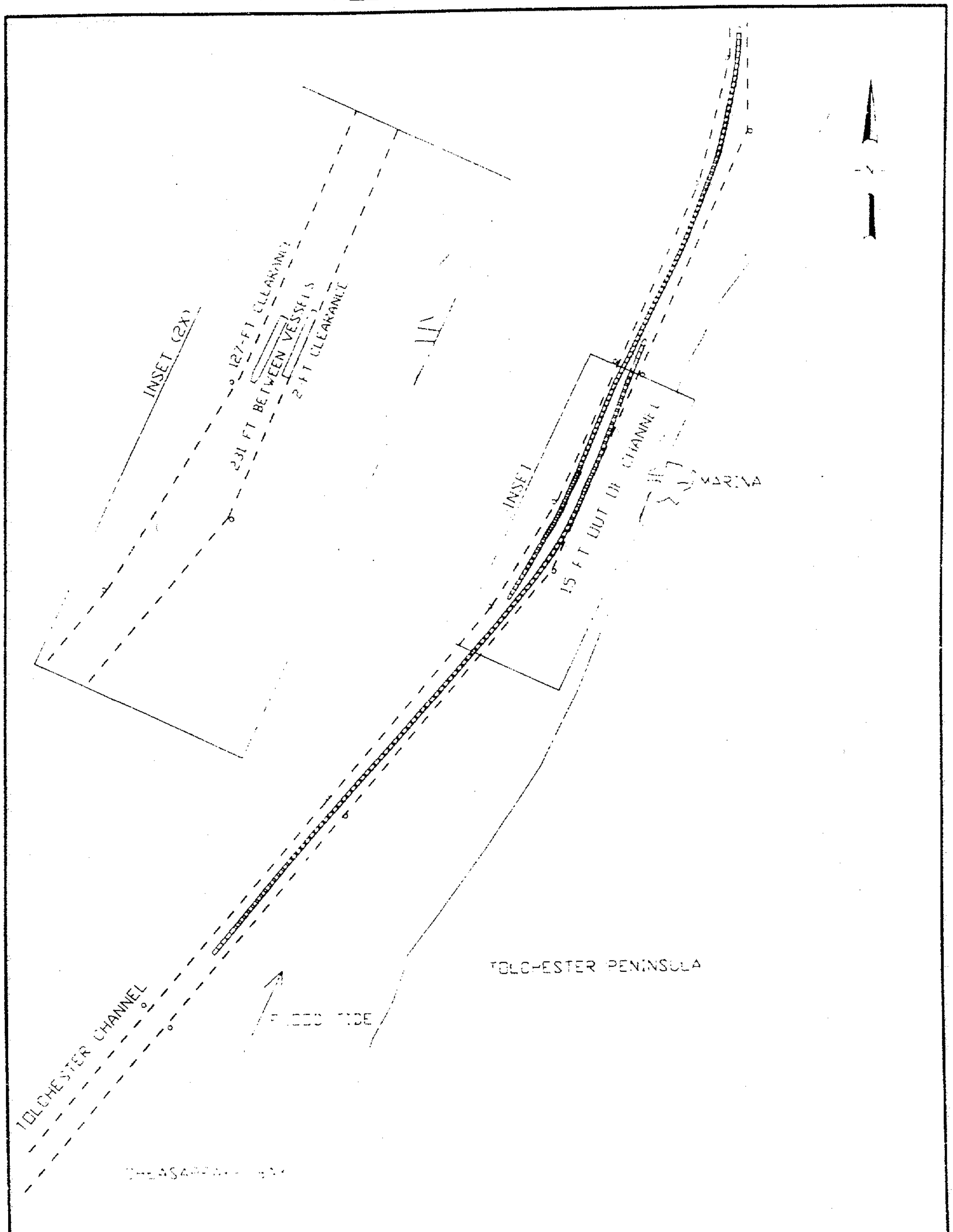


Plate 202

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

PRELIMINARY

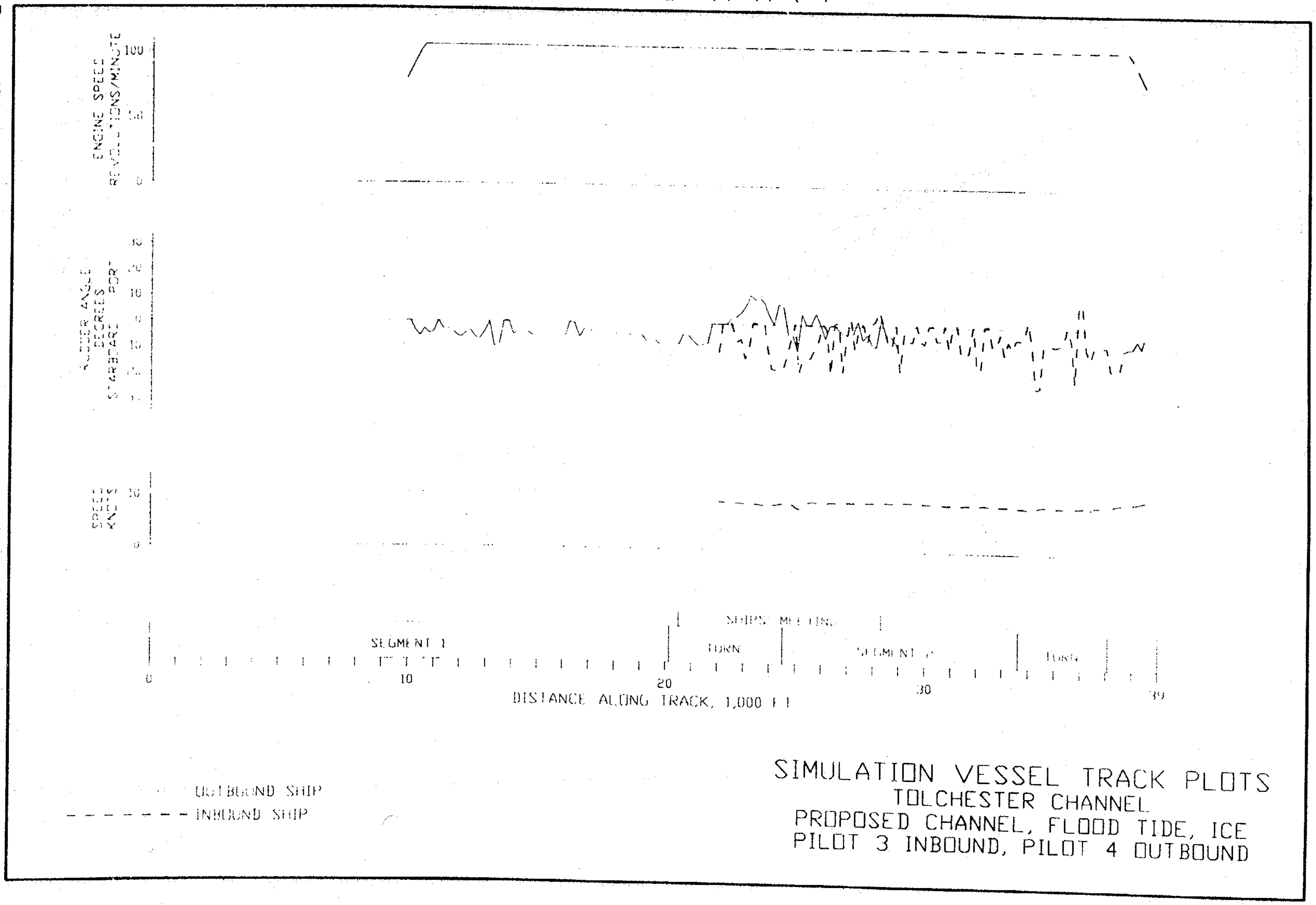
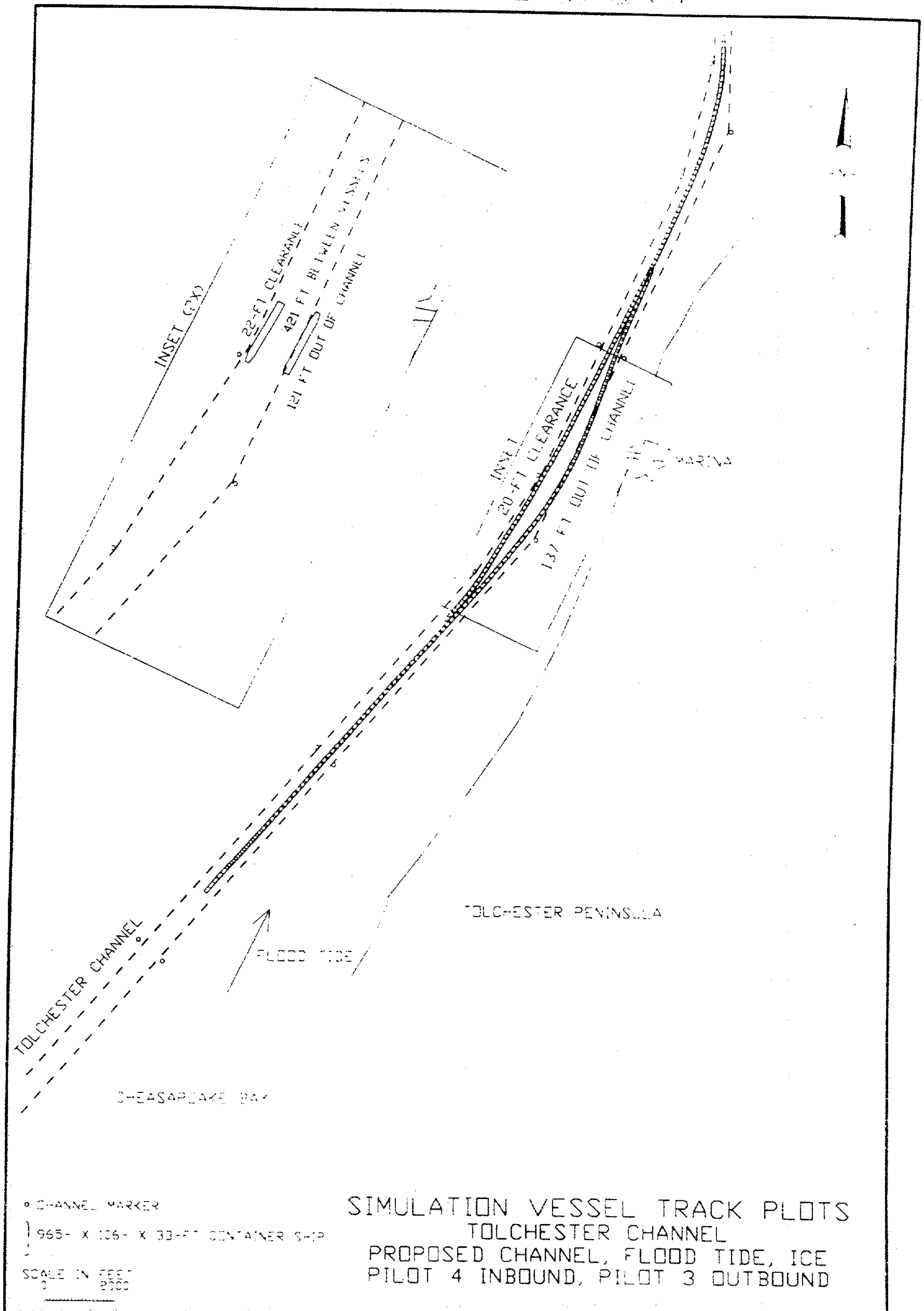


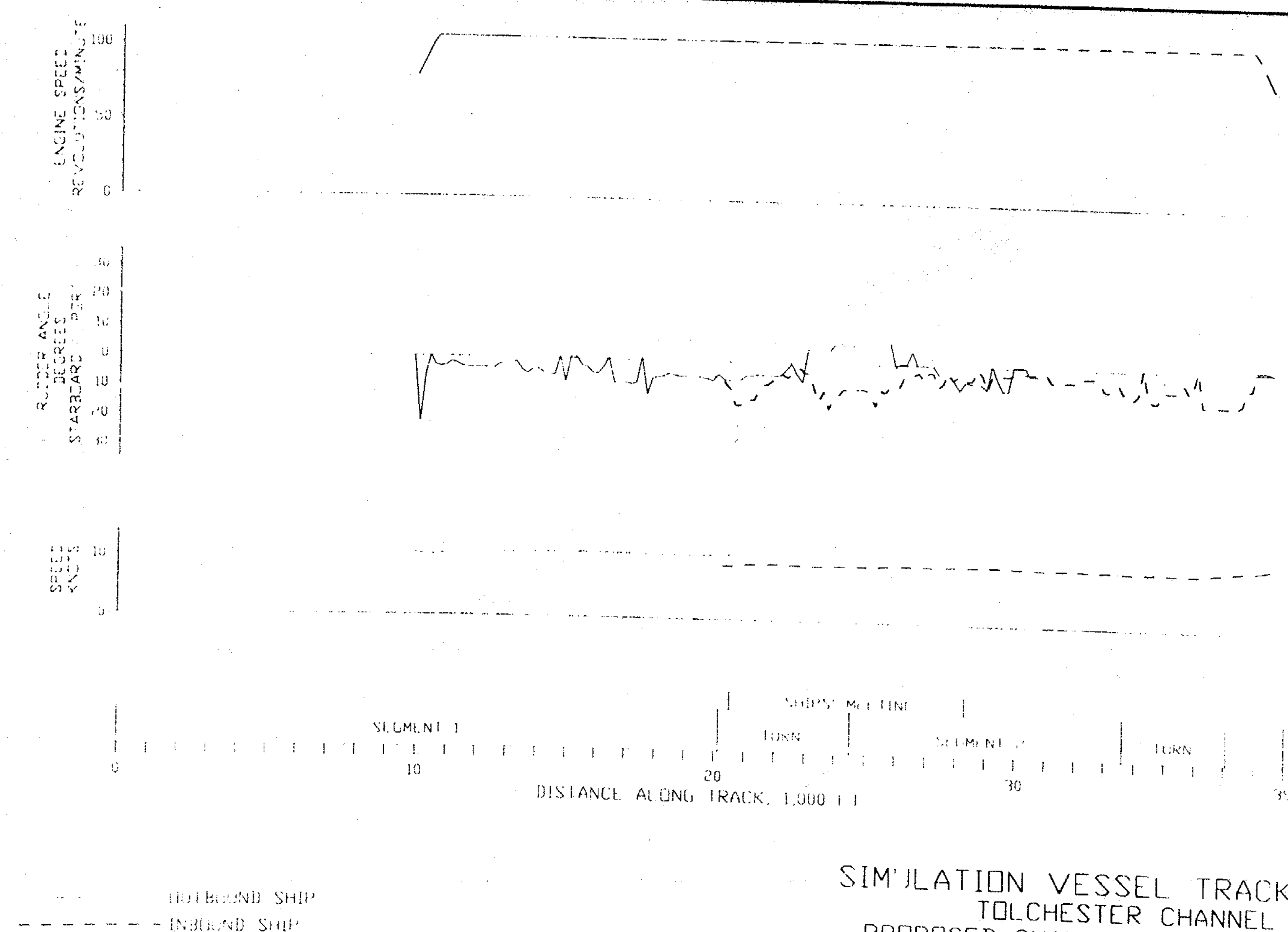
Plate 204

PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

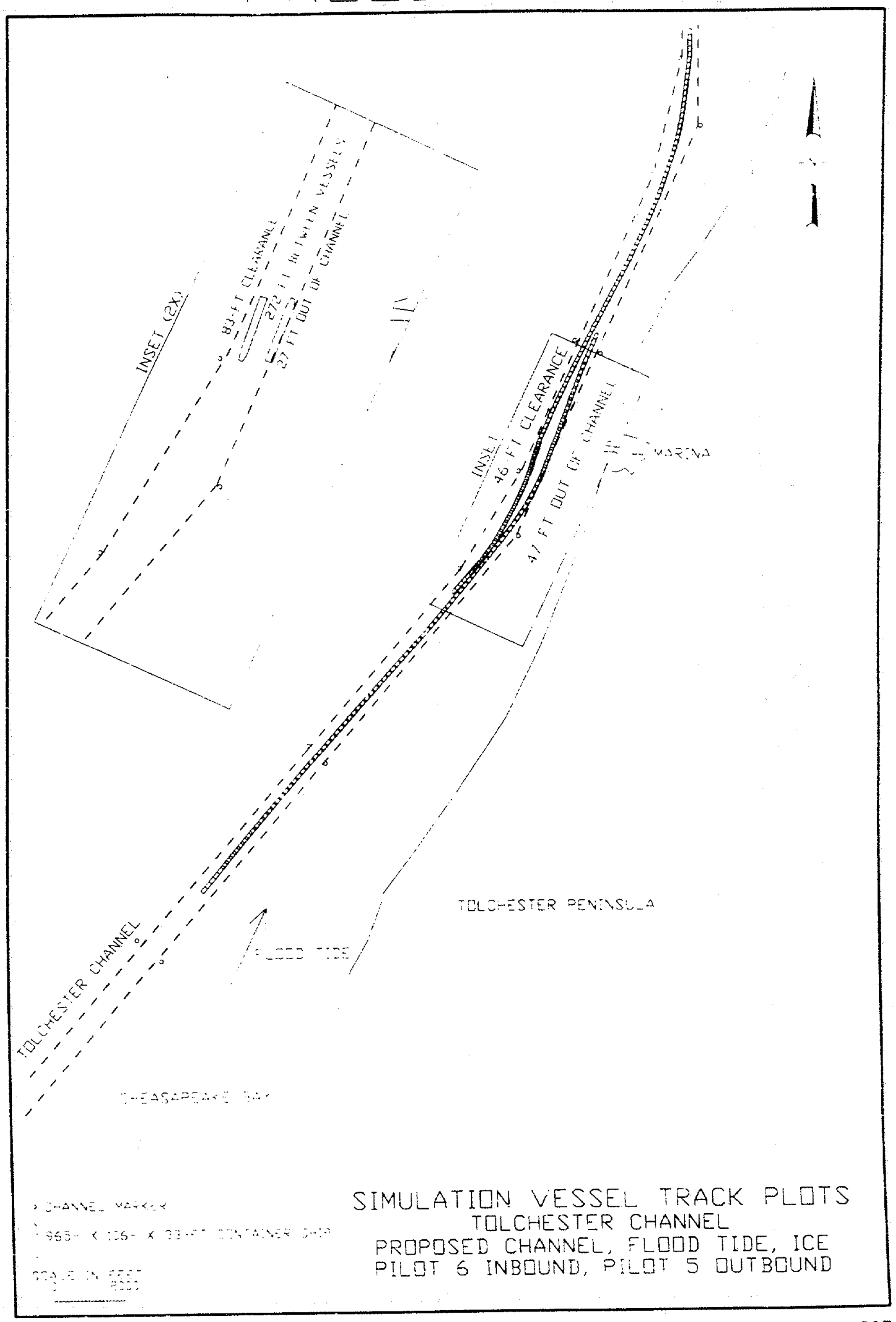
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 206

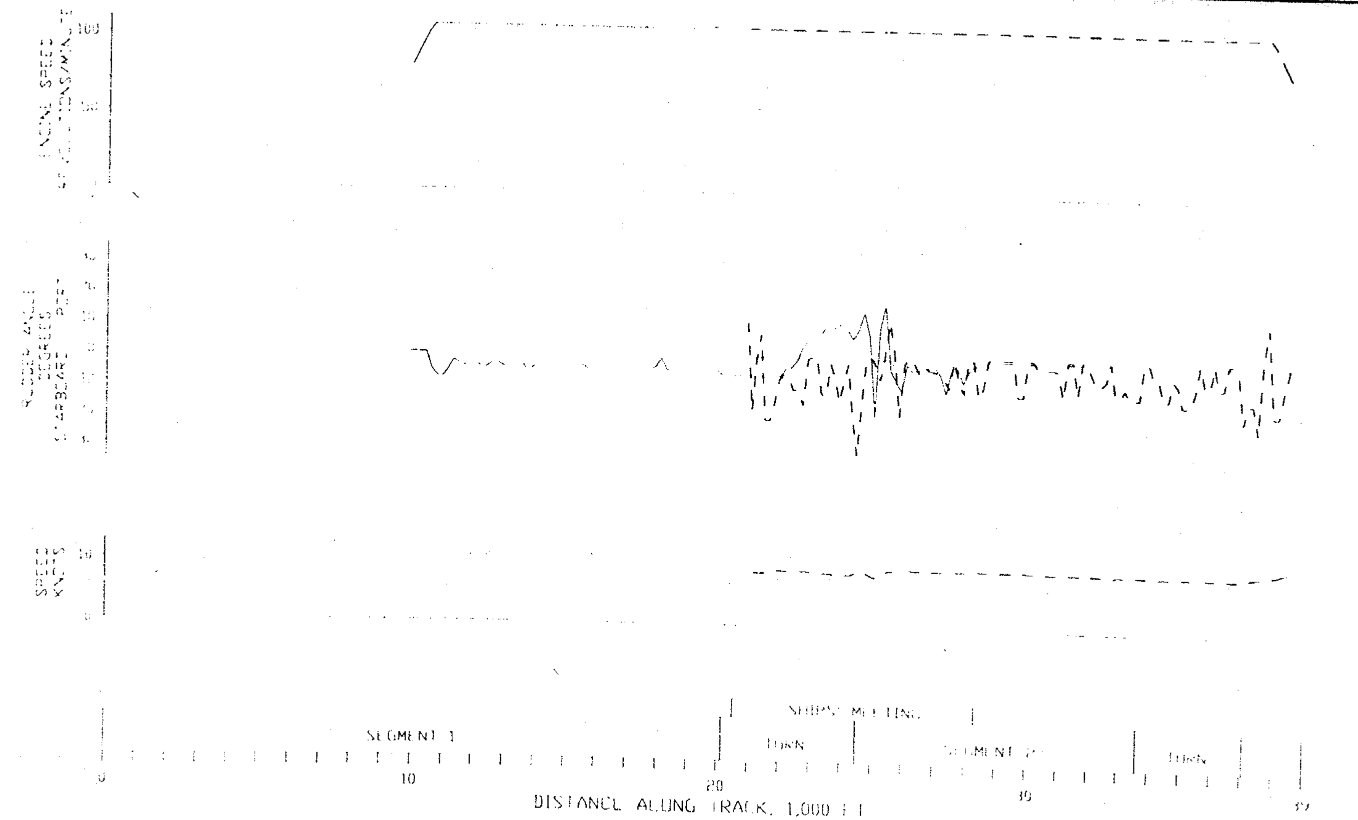
PRELIMINARY



SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 207

PRELIMINARY



OUTBOUND SHIP
- - - - - - - INBOUND SHIP

SIMULATION VESSEL TRACK PLOTS
TOLCHESTER CHANNEL
PROPOSED CHANNEL, FLOOD TIDE, ICE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 208

Appendix A Hydrodynamic Study

Introduction

Purpose. The purpose of the hydrodynamic modeling portion of this study is to develop a two-dimensional model of the Upper Chesapeake Bay that will statisfy the needs of a navigation study of the Brewerton Eastern Extension Channel widening and Tolchester Channel realignment. The navigation study will use the hydrodynamic modeling results for both the ship simulation and sedimentation portions of this study. The Upper Chesapeake Bay and its navigation channels are geometrically complex and are best studied using an unstructured numerical model. Given this fact and the lack of salinity stratification in the area, a two-dimensional (2D) vertically-averaged model is quite adequate for this navigation study.

Approach. A finite-element mesh that covered all of the Upper Chesapeake Bay from just downstream of the Chesapeake Bay Bridge near Annapolis, Maryland, upstream to the head of tide in the Susquehanna River and to just east of Chesapeake City, MD on the C&D Canal was constructed (Figure 1). All of the major geometric features that affect currents within the navigation channels were included in the mesh. This required the use of both triangular and rectangular shaped elements of various sizes. Sufficient refinement was provided throughout the mesh so as to be able to observe circulation patterns that might depart from existing conditions throughout the bay. Once the existing (base) conditions were determined, the various plan channel depths and widths were incorporated into the numerical model and plan conditions determined. Spring tide conditions were also determined to be the most important for the ship simulation and sedimentation portions of the study.

Model Description

TABS. TABS-MD is the name of a family of computer programs used in the two-dimensional modeling of hydrodynamics, sedimentation, and constituent transport in rivers, reservoirs, bays, and estuaries. The system was developed by the Hydraulics Laboratory at WES from the finite-element, hydrodynamic, and sediment transport models originally developed by Resource Management Associates, Inc., in Davis, California. Significant enhancements to the codes have allowed for applications to a wide class of computational hydraulics problems. Recent improvements to the system include the addition of a graphical user interface (FastTABS) which allows for quick editing of mesh geometry, simplified assignment of boundary conditions and model parameters, and sophisticated post-processing capabilities including color contour plots, velocity vector display and flow trace animations.

RMA-2. The hydrodynamic model, RMA-2, solves the depth-integrated equations for conservation of mass and momentum in two horizontal directions. The finite-element method, using Galerkin weighted residuals, is employed to solve the conservation of mass and momentum equations. Bottom friction is calculated using the Manning's equation, and eddy viscosity coefficients are used to estimate the effects of turbulence.

The finite-element mesh may contain quadrilaterals, triangles, or a mixture of the two; and each element may have parabolic sides. Elemental shape functions are quadratic for flow and linear for depth. Integration in space is Gaussian. Derivatives in time are replaced by nonlinear finite difference approximations.

The finite-element solution is fully implicit, and the set of simultaneous equations is solved by Newton-Raphson iteration. The solution is achieved using a front-type matrix inversion that assembles a portion of the matrix and solves that portion before assembling the next portion of the matrix. A description of the model is given by Thomas and McAnally (1991).

Modeling Procedures

Mesh Design. The numerical model was designed to allow accurate replication of the tidal circulation throughout the Upper Chesapeake Bay (Figure 1). The mesh was sufficiently refined to allow observation of this circulation throughout the entire Upper Chesapeake Bay, including the areas in and around the Brewerton Eastern Extension and Tolchester

Channels. This high level of resolution was included so as to insure that the impacts of the proposed changes to the channels could be studied at no farther than 300 ft intervals measured across the channel and 2500 ft intervals measured along the channel. The area around the Tolchester Channel was typically measured in greater detail due to the significance of the changes to the channel alignment.

Model geometry for the base condition was defined by the National Oceanic and Atmospheric Administration (NOAA) Charts 12270 (dated May 1990), 12272 (dated Nov. 1992), 12274 (dated Feb. 1993), 12278 (dated Feb. 1992), and 12281 (dated Jan. 1993) that were supplied by the United States Army Engineer Distrct, Baltimore (the District). The Brewerton Channel Eastern Extension plan conditions were constructed by moving base condition nodes to define the 550 foot and 600 foot widening plans. The mesh was designed with elements that incorporated both the base and plan conditions for the Tolchester Channel realignment. Nodal elevations for the affected elements were changed from the base to the different plan conditions in this region of the mesh. This provided for direct comparison of hydrodynamic and sediment variations between the base and plan conditions on a node-by-node basis in and around the Tolchester Channel area.

A high degree of resolution was provided in the mesh not only in the study areas but throughout the entire area of the Upper Chesapeake Bay covered by the mesh, including Baltimore Harbor and its approaches, the Chester River, and the Magothy River. With the low velocities encountered in the Upper Chesapeake, the relative importance of tidal volume is increased with respect to model accuracy. The high mesh resolution was included to ensure that the model accurately represented the tidal volume exchanges that naturally occur in the Upper Chesapeake Bay. Additionally, this would allow for future studies of the Upper Chesapeake Bay to be conducted if requested without significant increase to the mesh generation or model run times for this study.

Boundary Conditions. Both tidal and historical flow boundary conditions were used for this study. A harmonically derived tidal signature, synthesized from National Ocean Service (NOS) harmonic constituents based on an analysis of historic tides for the Sandy Point, Maryland recording station, was used at the downstream boundary of the mesh. At the upstream end, a constant inflow of 35,000 cfs was used for the Susquehanna River. This value represents an average discharge value for the river at this location based on yearly average data available. Because of the high degree of variability and tidal fluctuations between the

Chesapeake and Delaware Bays, no boundary condition was assigned to the C&D Canal. The tidal flows in the Chesapeake are significantly higher than the flow contributions from the Susquehanna River and the C&D Canal. It was therefore detemined that the lack of exact flow value boundary conditions at the Susquehanna and C&D Canal would be a source of error in the overall model results but would not significantly affect the hydrodynamic conditions in the study areas.

The location of the downstream boundary of the mesh was chosen to be the narrow neck of the bay just south of the Chesapeake Bay Bridge and just upstream of the mouth of the Severn River. This location was chosen because it represents a confined part of the bay where the bathymetry and velocity distribution is well defined. In addition, there are no severe lateral gradients across the boundary which would cause numerical instabilities in the model. Finally, there were two NOS tidal recording stations nearby, Sandy Point and Greenbury Point, from which harnonic tidal data could be obtained for the boundary condition. Trial runs of the base condition indicated that using the Sandy Point tidal data produced the most accurate results. Figure 2 depicts the synthesized harmonic tidal data that was used as input for the model study.

A 5-day spring tide was chosen from the synthesized harmonic tidal data from June 23 through June 28, 1994 at half-hour timesteps. This included a 20-hour model spin-up time and four days of the spring tide. The 20 hours of spin-up is necessary to remove the influence of the initial conditions of water surface elevation and velocity, which are initially set to constant values throughout the finite element mesh. Hour 0 of the hydrodynamic study was set equal to 03:00 on 23 June 1994.

The location of the upstream boundary of the mesh in the Susquehanna River was chosen at a location just downstream of the Conawingo Dam which is considered to be the head of tide for the Chesapeake Bay tidal influence on this river. As well, the mesh was extented to the head of tide for all river and streams of significant size and volume in the Upper Chesapeake Bay. The decision to incorporate the portions of the rivers influenced by tidal fluctuations in the bay was dictated by the need to accurately reproduce the tidal volume exchanges mentioned earlier. Since the Susquehanna River represents the only major inflow to the Upper Chesapeake Bay, with the noted exception of the C&D Canal, it was the only upstream inflow boundary condition specified in the model.

Model Verification

Procedure. Very little model adjustment is required to verify numerical models if the governing equations describe the problem, sufficient resolution is used, and the boundary conditions are accurate and meaningful. Indeed, if the mesh is properly constructed and reasonable boundary conditions are used, the remaining adjustment of coefficients should provide only minor variations in the output, given that they were based on real-world phenomena and not numerical expediency.

In RMA-2, only two coefficients can be adjusted in the verification process: elemental Manning's n for roughness and eddy viscosity for turbulence characteristics. Both the scientific literature and a significant amount of experience in verifying numerical models suggest that a case can be made for assinging global Manning's n values based not only on the type of water body modeled and the flow conditions, but also as a function of depth within the model. The values used in this model study are given in Table 1. Initially, slightly differing values were used for the 6-11, 12-17, 18-34, and shipping channel depth categories but sensitivity analyses revealed that the best verification could be obtained with these values.

Element Depth (feet)	Manning's n	Eddy Viscosity (lb-sec/ft^2)
0-5	0.030	100
6-11	0.018	100
12-17	0.018	100
18-34	0.018	100
Shipping Channels	0.018	100
Shallows near Kent Island	0.035	150

Table 1. Eddy viscosity and Manning's n values for specific depth intervals used in modeling study.

Eddy viscosity coefficients are the only other adjustment coefficients used in RMA-2. In theory, they are designed to account for turbulence that is indeed present in the prototype but cannot be modeled unless a more rigorous and significantly more expensive turbulence closure model is used. A common manifestation of using values that are too large is the smearing of velocities to the point of lateral uniformity when lateral gradients in the velocity fields are expected.

A significant amount of experience in both numerical and physical flumes as well as prototype scale problems indicates that, in general, the lower the eddy viscosity value, the better the results. In prototype scale problems of estuaries, it is rare to have stable model results with eddy viscosity coefficients that are too small. For economic reasons most grids are sufficiently coarse to require a certain amount of viscosity to maintain model stability. In most cases, this minimum amount of viscosity for stability is close to that required based on the physics of the problem. All models used today in computational hydraulics contain some amount of viscosity, whether it is supplied manually to the simulation or it is intrinsic to the solution technique. It is not an alarming consideration provided that reasonable values are used. The eddy viscosity values used in this study were isotropic in the xx-, xy-, yx- and yy-directions and are given in Table 1.

The last depth category is specific to the shallow area of the bay located just upstream of Kent Island near the mouth of the Chester River. This region of the numerical model requires special attention for stability reasons. Modeling experience has shown that sudden expansions and contractions, especially when located near to a model boundary condition, can lead to numerical stability problems. Such a condition exists at this location in the bay with the Chester River entering the bay from the East and the Magothy River entering from the West. The problem is further exacerbated by the rapid change in depth on the west side of Kent Island. The shipping channel, over 60 feet in depth in this area, passes near to the shore. The combination of the sudden expansion in the mesh geometry near the tidal input boundary condition and the rapid depth changes near Kent Island required the use of a higher Manning's n and eddy viscosity value for the shallow regions of the mesh in this area.

Tide Verification Results. Evidence that reasonable verification procedures were used is shown in the model results. Five verfication points were chosen at various locations in the bay for which NOS harmonic synthesis data was available. These stations are located at or near Havre de Grace, Fishing Battery, Pooles Island, Tolchester, and Sevenfoot Knoll (see Figure 3). Figures 4 through 8 give a comparison of model versus harmonic synthesis values for these verification points. Agreement between model and the harmonic tide data is good for all five locations in the bay. Because of the length of the bay, there is a significant lag in tidal phase from downstream to upstream and this is reflected in both model and prototype measurements for these stations. Slight differences in the tide elevations at the lower high and low waters can be explained by the exclusion of the C&D Canal tidal influences. Since the higher high and low tides were most important for this study, it was deemed more important to accurately capture these fluctuations in the model.

Velocity Verification Results. Velocity verfication was achieved by using the base condition hydrodynamic modeling results at maximum spring ebb and flood tides in the WES Ship/Tow Simulator as described in the navigation portion of this report.

Model Results

Tide Results. Figures 9 and 10 give a comparison of the base and three plan conditions at the two study areas. An examination of the tidal results from these numerical model runs indicate that there is virtually no difference in phase, amplitude or plane between the base and plan conditions. This was somewhat predictable since the study areas are located in relatively wide portions of the bay where the tide is unlikely to be significantly affected by relatively minor changes in the bathymetry.

Velocity Results. Analysis of the velocity results for the base and plan conditions revealed that there was no difference in the velocity magnitudes or directions for the Brewerton Channel Eastern Extension. As well, at points located just downstream and just upstream of the Tolchester Channel, there was no change in the velocity magnitudes or directions. As expected, there were changes in the channel velocities between the existing and proposed channel portions. However, these velocity changes are small (less than .21 fps) and, as reported in the navigation portion of this report, the velocities were determined to not provide a hindrance to safe navigation of the channel.

Conclusions

Numerical model simulations of the base and plan conditions in the Upper Chesapeake Bay indicate that the proposed navigation improvements to the Brewerton Eastern Extension and Tolchester Channels will have little effect on tidal circulation in the bay. Base and plan hydrodynamic data sets were produced with the numerical model that were used in the ship simulation and sedimentation portions of this study. The results successfully reproduced the variable current magnitudes and directions in the navigation channel as determined by experienced bay pilots and reported in the navigation phase of this study.

References

Thomas, W. A. and McAnally, W. H., Jr. (1991). "Users' manual for the generalized computer program system: open-channel flow and sedimentation, TABS-2," Instruction Report HL-85-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

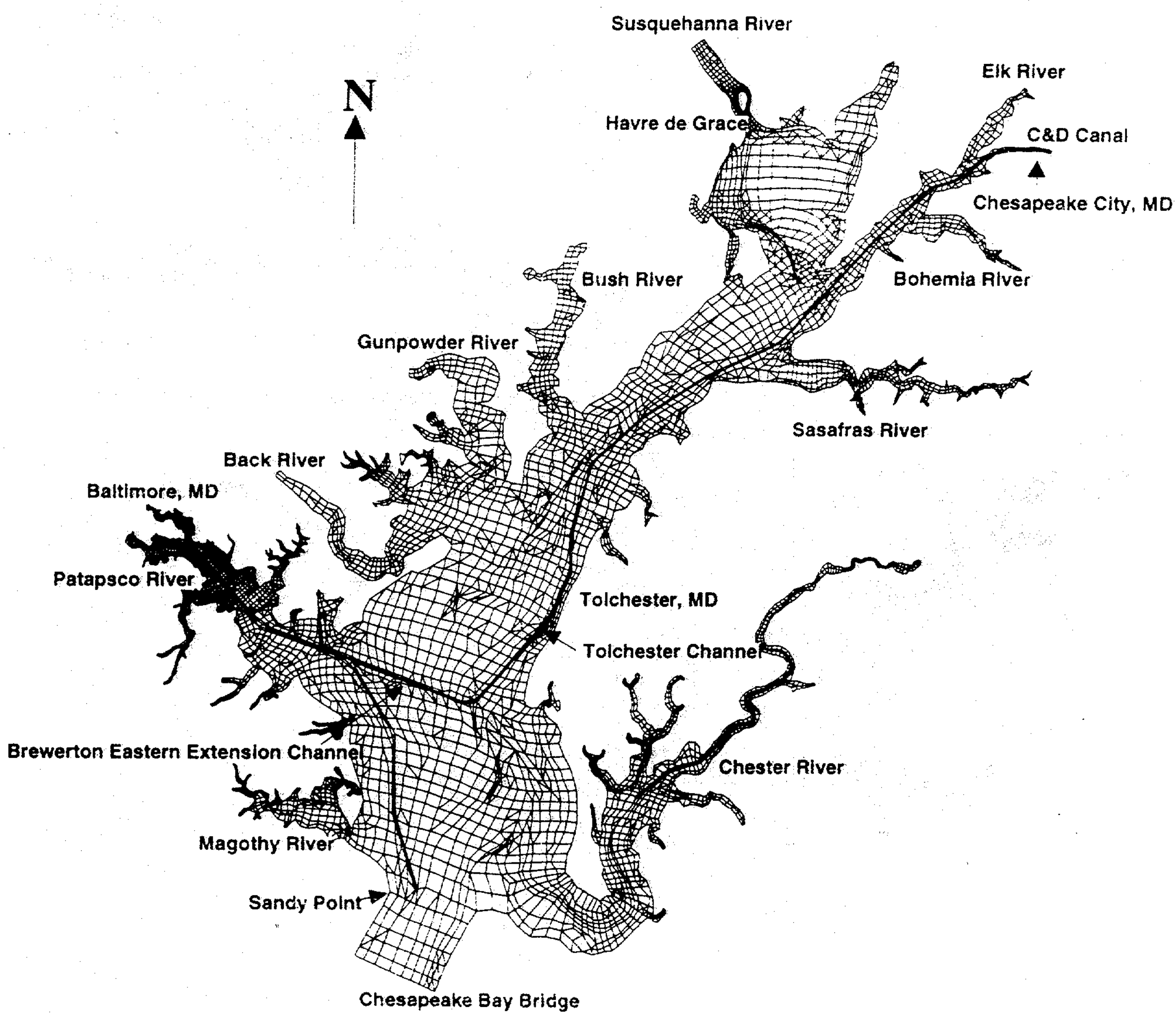


Figure 1. Hydrodynamic Modeling Study Numerical Mesh

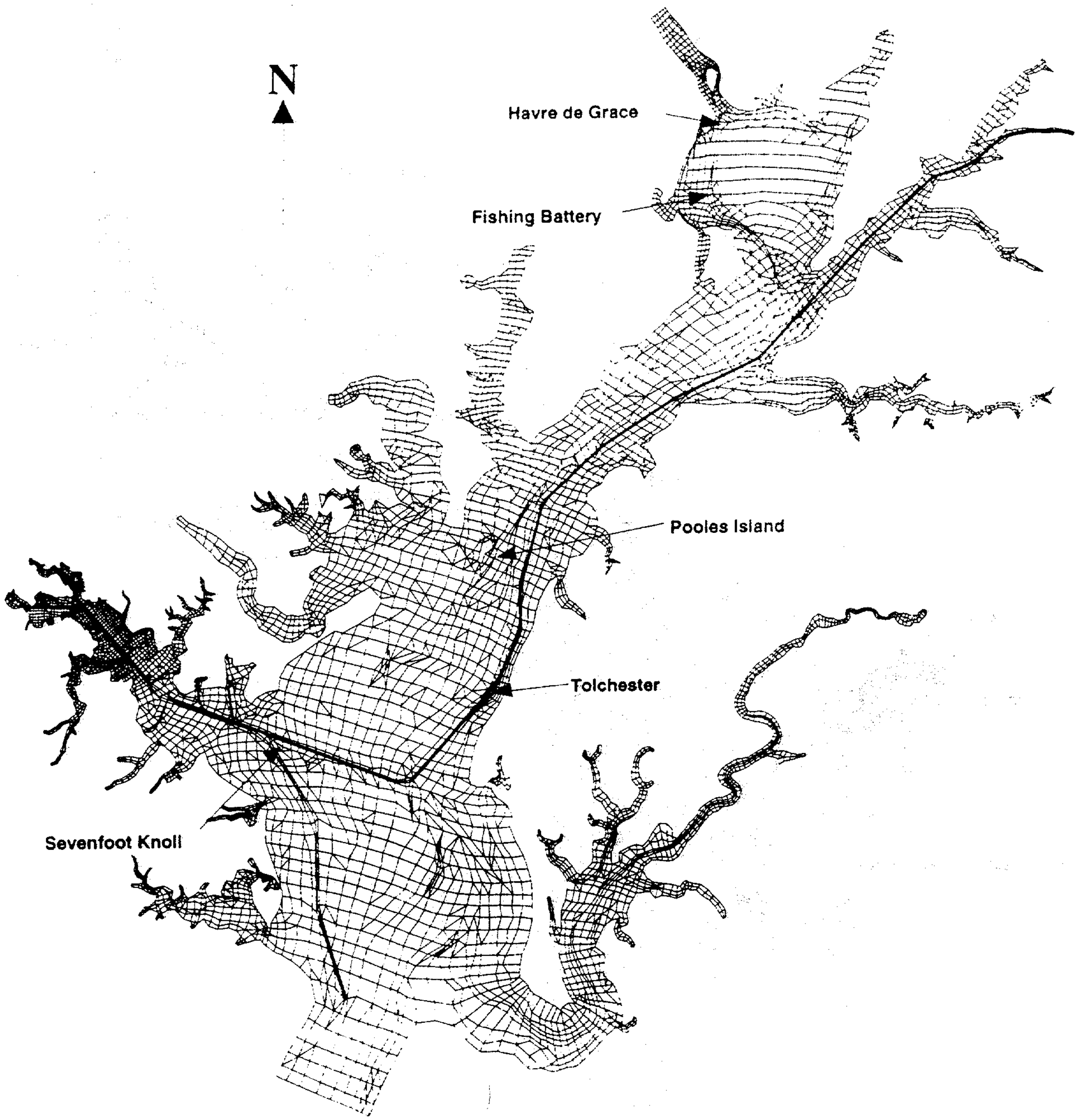


Figure 2. Location of Verification Points For Hydrodynamic Study

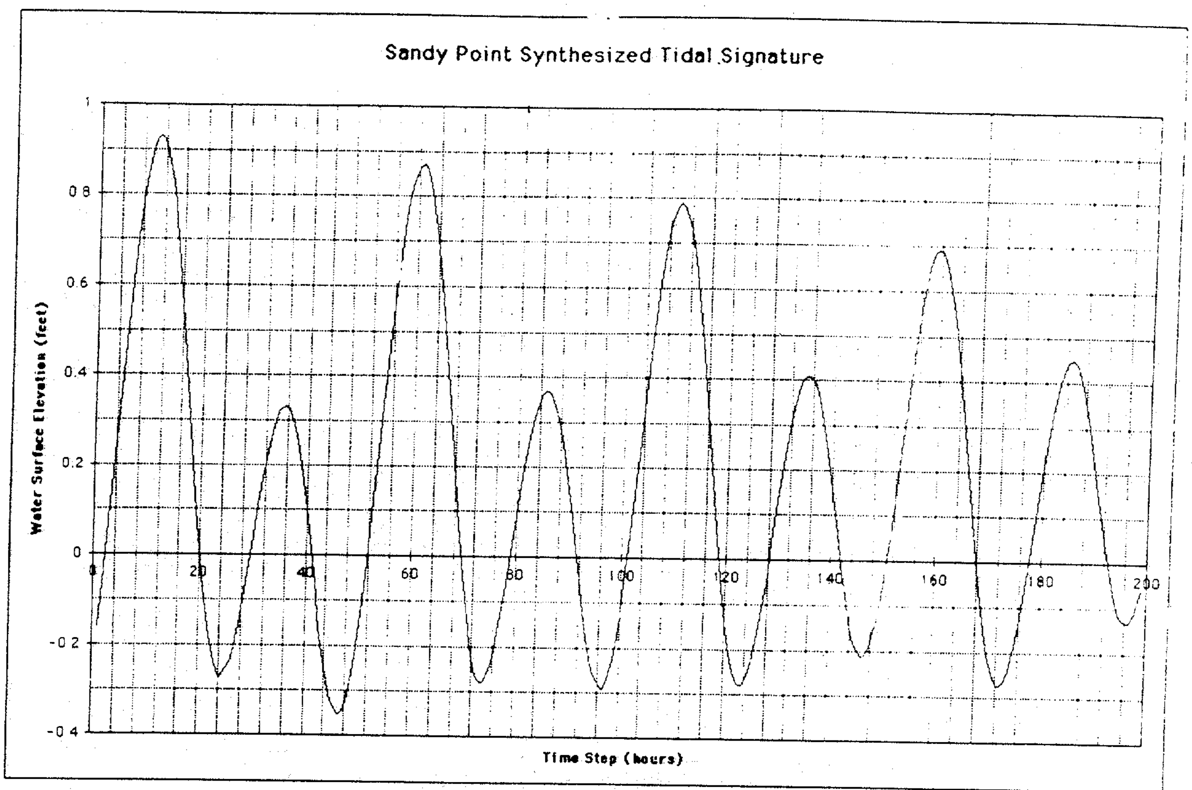


Figure 3. Input Tidal Signature Boundary Condition

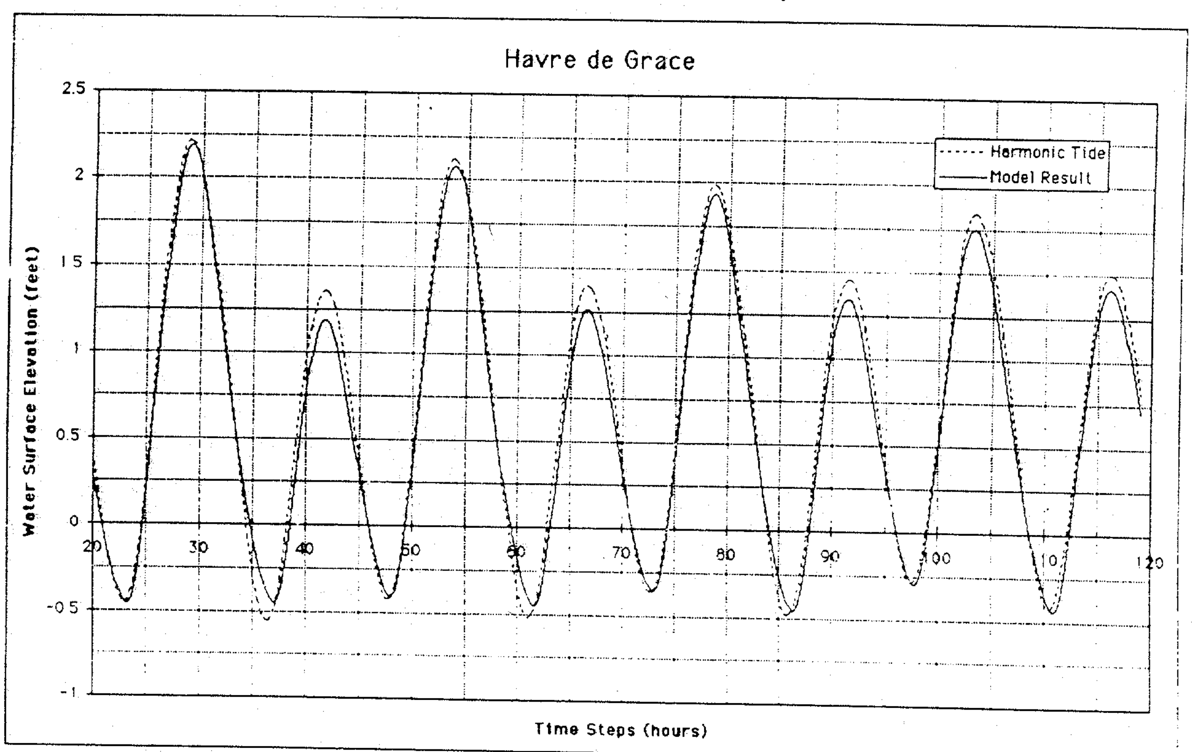


Figure 4. Comparison of Synthesized Harmonic Tide To Model Results at Havre de Grace

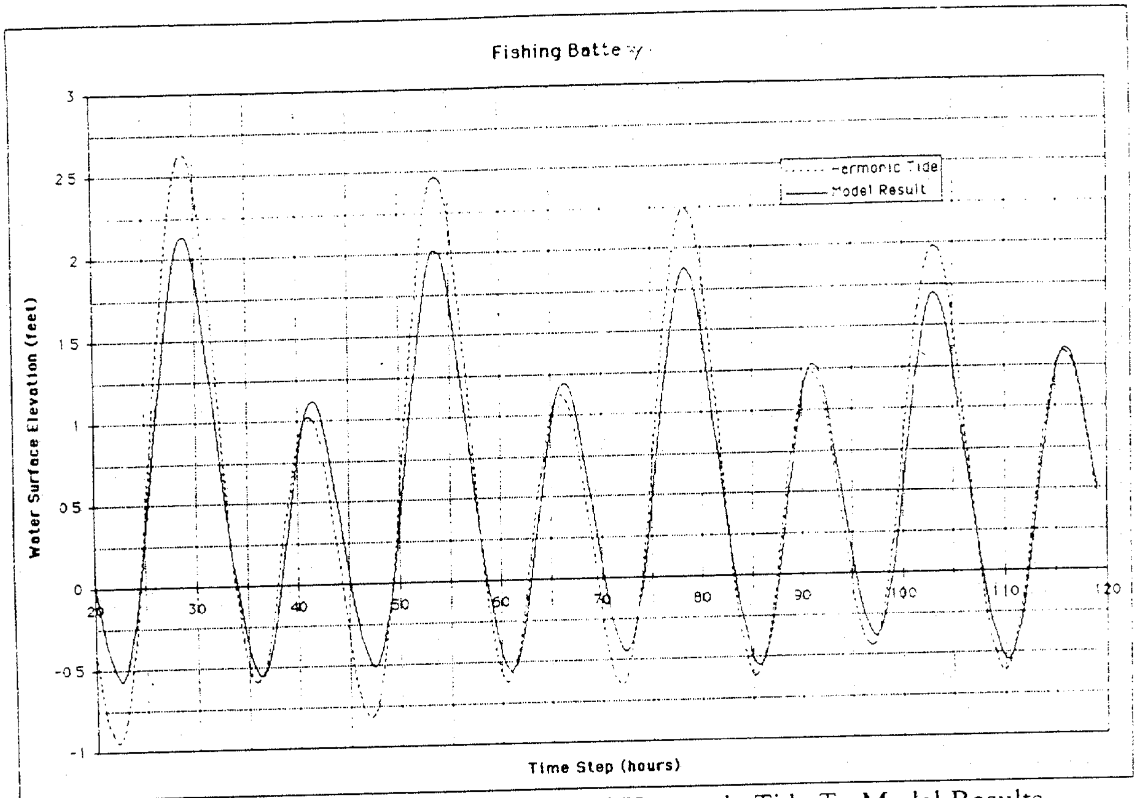


Figure 5. Comparison of Synthesized Harmonic Tide To Model Results at Fishing Battery

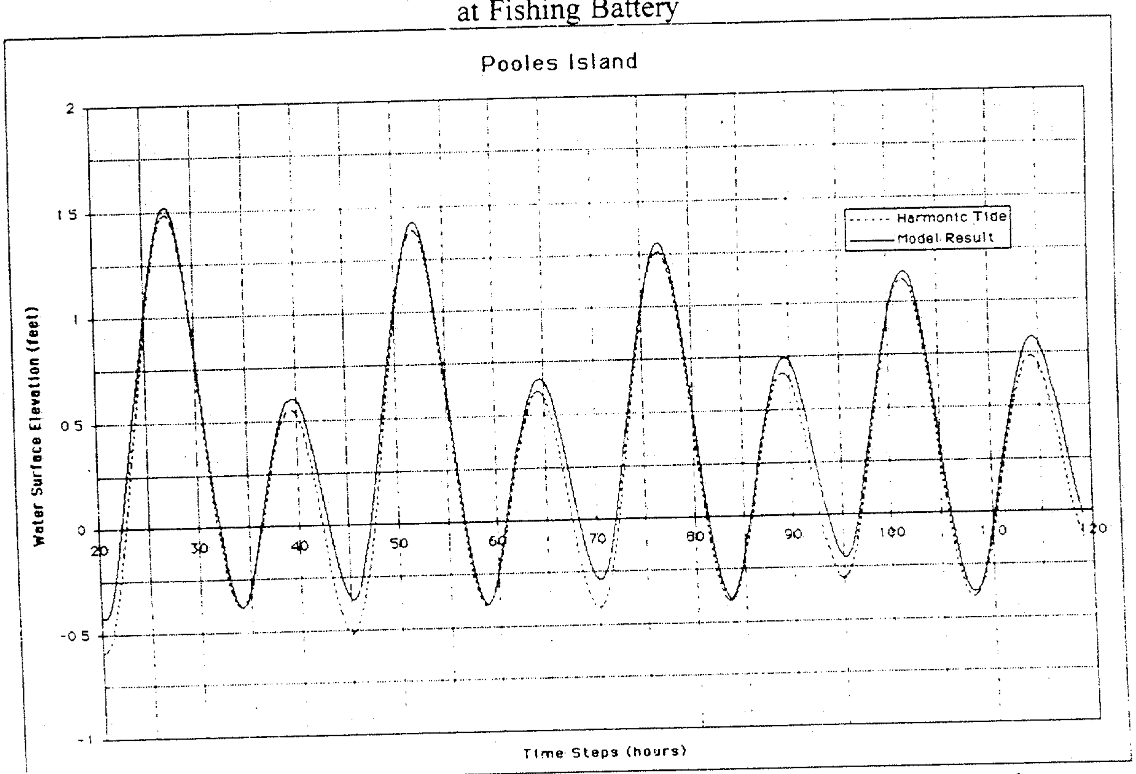


Figure 6. Comparison of Synthesized Harmonic Tide To Model Results at Pooles Island

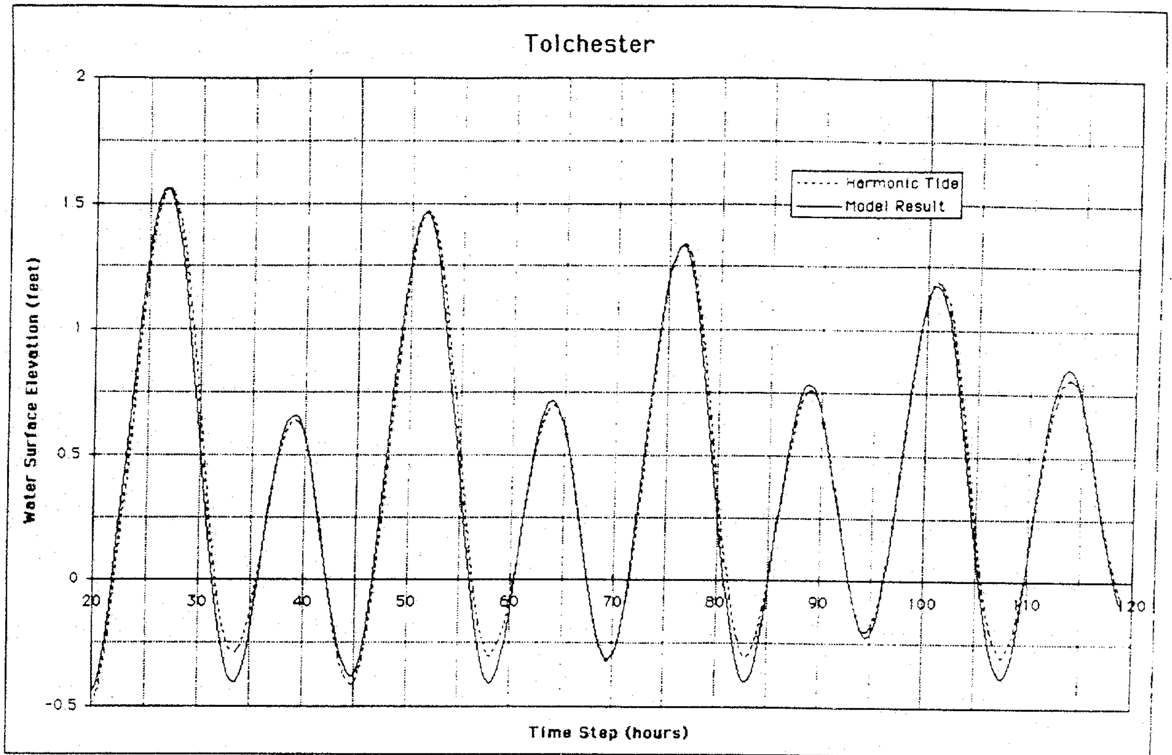


Figure 7. Comparison of Synthesized Harmonic Tide To Model Results at Tolchester

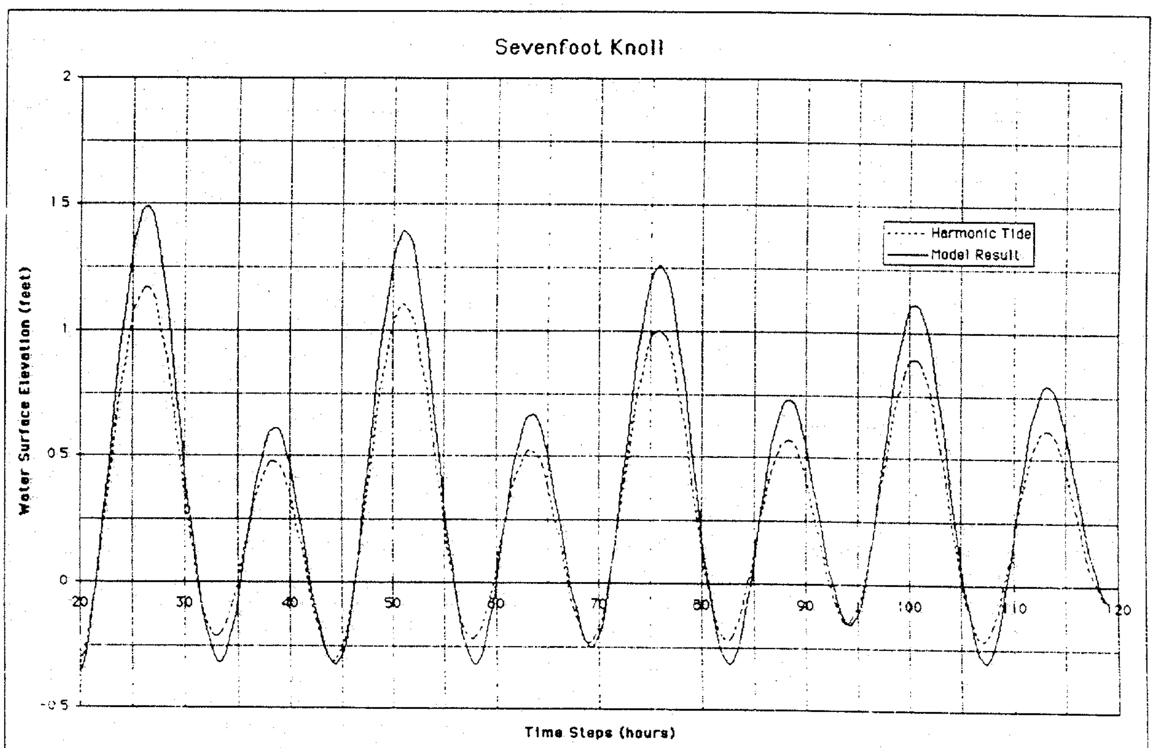


Figure 8. Comparison of Synthesized Harmonic Tide To Model Results at Sevenfoot Knoll

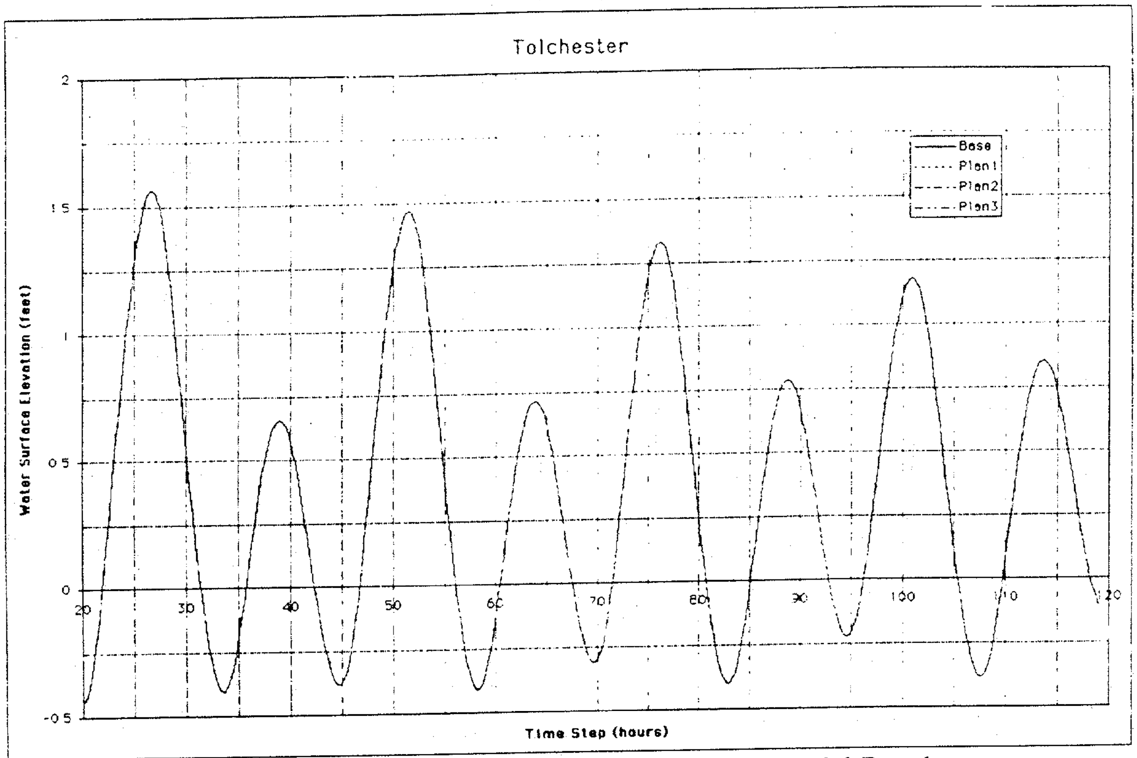


Figure 9. Comparison of Base to Plan Condition Model Results at Tolchester

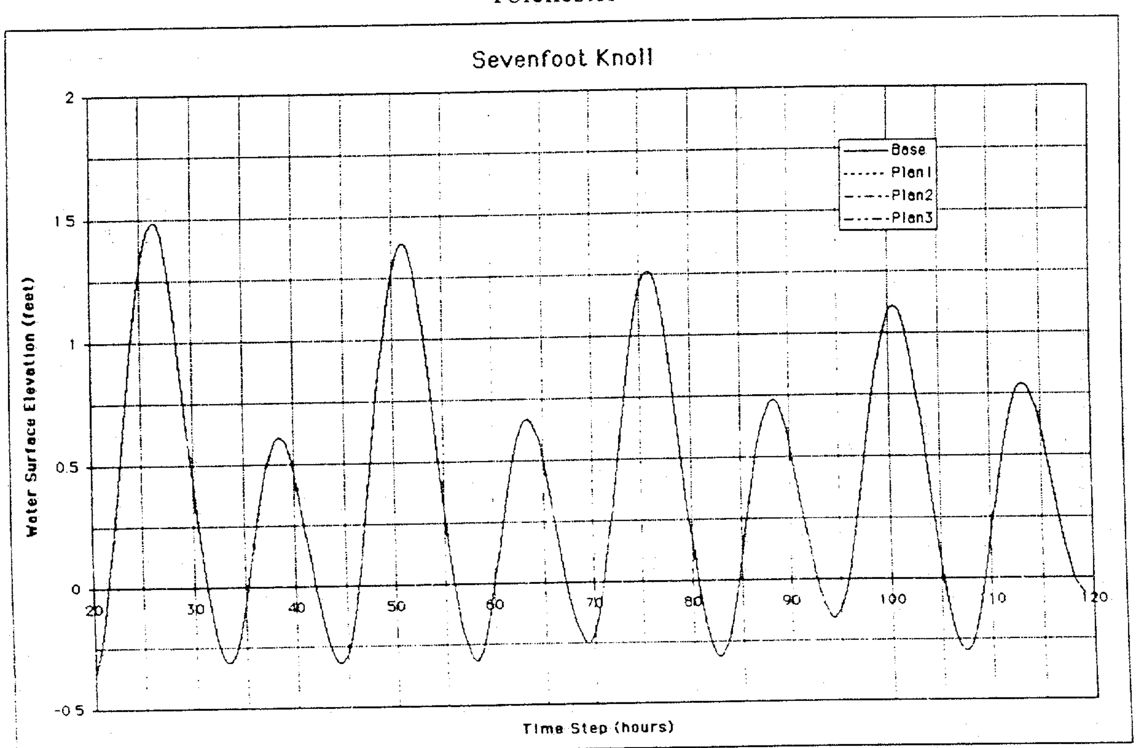


Figure 10. Comparison of Base to Plan Condition Model Results at Sevenfoot Knoll

APPENDIX B: SEDIMENTATION STUDY

BREWERTON AND TOLCHESTER CHANNEL MODIFICATIONS

(by Allen Teeter, Chris Callegan, and Claire Livingston)

INTRODUCTION

The U.S. Army Engineers District, Baltimore (CENAB), is evaluating improvements to two navigation channels in Chesapeake Bay at the request of the State of Maryland and the Maryland Pilots Association. The U.S. Army Engineer Waterways Experiment Station conducted navigation and sedimentation studies of the existing and proposed channels for CENAB. The channel modifications could potentially affect sedimentation and maintenance dredging requirements. A numerical sedimentation study was therefore performed to gage these possible effects as described in this appendix.

The Brewerton Channel Eastern Extension is a straight channel about five nautical miles long extending across Chesapeake Bay from the approach to Baltimore Harbor. The Tolchester Channel is about six nautical miles long, following the eastern, deep area of Chesapeake Bay. The locations of these channels in Chesapeake Bay are shown in Figure A-1 and A-2.

The Brewerton Channel Eastern Extension has cross currents which can reach over one knot. Pilots restrict the combined beams of meeting vessels to 160 ft. Some large vessels choose the longer route through Swan Point and Craighill Channels (Figure A-2) to avoid the Brewerton Channel Eastern Extension. A widening to 600 ft has been proposed for the Brewerton Channel Eastern Extension, and is evaluated for sedimentation effects in this study.

The Tolchester Channel has an "S-Turn" which requires five course changes in three nautical miles. Navigation difficulties occur here because of a lack of range lights, high currents, and because buoys may become obscured. A channel straightening in the area of the "S-Turn" has been proposed, and is evaluated for sedimentation effects in this study.

This sedimentation study used currents developed for the navigation study, as described in Appendix A. Currents were computed numerically for a number of tidal cycles and used as input to a numerical sedimentation model. The models used in both the hydrodynamic and sedimentation studies were two-dimensional, depth-averaged components to the U.S. Army Corps' TABS-MD modeling system (Thomas and McAnally, 1985).

SEDIMENT CONDITIONS AT THE SITE

Chesapeake Bay covers extensive areas of the Atlantic Coastal Plain that consists of bedrock overlain by thick sequences of sand, silt, and clays. Deposits dip seaward and form the continental shelf. While bedrock outcrops near Baltimore, bedrock is 600 m deep at Cape Henry in the southern portion of the Bay. Sea level fluctuations over geological time have caused deep erosion and channel cutting followed by sediment filling. The present relatively high sea level stand has flooded the former river valleys to create the Chesapeake and other Bays. Sediment filling was first by sand and gravel deposits and finally by soft clays and silts (CENAB 1995). Much of the sediment filling in the upper Chesapeake Bay occurs during rare, high river floods (Schubel 1984).

Brewerton Channel Eastern Extension sediments were found in 1960's and 1985 cores to be predominantly (dark) grey silty clay (CH) with minor amounts of clayey silt, organic clayey sand, sandy clay, and organic clayey silt (CENAB 1995). The Tolchester Channel had predominantly black organic silt (MH) with minor amounts of organic silty clay and silt indicated in 1960's cores. Surficial samples were mainly black organic clayey silt (MH).

During normal conditions, sediment is mobilized and moved around the bay by wind waves and tidal currents. Sanford (1993) observed turbidity, salinity, wave height, temperature, and bottom currents at a 3.5-5.5-m-deep dredged material disposal site in upper Chesapeake Bay during the winters of 1990 and 1991. Halka et al. (1994) also studied resuspension of sediments at a disposal site in northern Chesapeake Bay. The studies agreed that winter storms caused resuspension and suspended particulate concentration peaks 3-5 times higher than normal maximum tidal currents caused. Background suspended material concentrations varied inversely with salinity and directly with the flow of the Susquehanna River, indicating that river inflow is important to these levels

Typical background concentrations of total suspended particulate (TSP) were 0-8 mg/l during September 1991, 2-18 mg/l for September 1992. Resuspension peak values of TSP were 5-25 and 35-45 mg/l for tides and storms, respectively. During Tropical Storm Danielle in September 1992, TSP values reached 60-80 mg/l, and after the storm values climbed to 120 mg/l. These data are representative of normal background and resuspension levels exclusive of dredged material resuspension.

CHANNEL DREDGING REQUIREMENTS

Both the channel dimensions and maintenance dredging requirements for Tolchester and Brewerton Extension Channels have changed over the years. Brewerton Channel Eastern Extension was constructed to 27-ft by 400-ft in 1948, and enlarged to 35-ft by 450-ft in 1988. A section was widened to 600-ft wide in 1991. Advenced maintenance dredging to 37 ft was performed in the Brewerton Channel Eastern Extension in 1992. Figure A-3 shows annual dredging values computed by averaging dredging volumes over the intervals between dredgings

Tolchester Channel was constructed to 35-ft by 450-ft in 1968 and enlarged to 35-ft by 600-ft in 1981. Minor widening of the turns and advanced maintenance dredging was performed to a depth of 37 ft in 1992. Figure A-4 shows the average annual dredging per year.

Because of the recent new-work dredging and advanced maintenance on both channels, it is difficult to estimate current annual dredging requirements with certainty. New-work often causes channel and side-slope adjustments over a period during which maintenance dredging is abnormally increased. New-work dredging has been performed in both channels during the late-1980's and 1990's, and apparently insufficient time has passed for the new channel geometries to stabilize with respect to maintenance dredging.

The Brewerton Extension was apparently not maintained between 1971 and 1986, and average annual dredging requirement was merely 22,000 cu yds per yr. Annual average dredging was computed as the average over the years between successive dredgings, as described earlier, since maintenance was not required every year. Maintenance dredging was required three times between 1987 and 1995, with an average of 419,000 and standard error of 62,000 cu yds per yr, over this period.

Tolchester dredging increased from an average or 27,000 cu yds per yr for the period 1969-1980, to 215,000 cu yds per yr for 1982-1986 after channel enlargement from 450-ft to 600-ft width in 1981. Since 1987 the channel has been maintained twice and maintenance requirements have averaged 95,000 cu yds per yr.

SEDIMENT MODEL ANALYSIS

For this study, the numerical finite-element sedimentation model SED2D (Roig et al. 1996) was implemented using the same numerical mesh as, and results from, the hydrodynamic modeling effort described in Appendix A to predict the erosion, transport, and deposition of fine sediments in the system. Figure A-5 shows the model mesh. The sediment model SED2D requires information on the distribution of settling, erosion, and depositional properties in the system. Initial and boundary suspended sediment concentrations are also required and were set to values cited earlier for tidal resuspension conditions.

The SED2D model uses a layered bed structure to characterize the density and erodibility horizontally and with depth in the bed. Erodibility of the bed depends on the threshold or critical shear stress for erosion of the material, and an erosion rate constant. The erosion threshold controls the level of shear stress at which erosion begins, and the erosion rate constant controls how rapidly sediments erode with shear stress in excess of the threshold value. For a certain erosion rate (mass per unit area), the model computes the change in bed elevation based on the dry density of the bed layers.

The underlying assumption of the modeling approach was that sediments are resuspended periodically by storms, are transported around the system, and then redeposit. As described earlier, wave resuspension during storms has been found to produce much more sediment resuspension than produced by tidal currents. Instead of using storm conditions, the same effect was produced in the model by imposing initial conditions such that sediment would be resuspended during a high spring-range tide early in the model simulations. The sediment model was operated over a spring tide to resuspend bed material then over a sequence of tides of varying, but lesser amplitudes, which transported sediment around the system and redeposited it during times of weaker tidal currents.

The first phase of the modeling was to adjust sediment parameters in the model. These adjustments were made based on experience and several dozen sensitivity model runs each performed over four tidal cycles. Model results were compared to shoaling rates by extracting bed elevation changes and model element areas from model result files. Deposited sediment volumes were summed over the model elements in the study channels and normalized to annual shoaling rates. The final adjusted sediment input data as they appeared in the model input file are shown in Figure A-6.

After the model adjustment phase, model runs were performed for ten-tidal-cycle periods, existing and plan conditions, using the same sediment characteristics. Model shoaling for the Brewerton Extension and Tolchester base-condition channels was 76,940 and 74,235 cu yds per yr, respectively. For comparison, Tolchester Channel maintenance dredging has fallen since after the channel enlargement of 1981. The most recent Tolchester dredging (1994) was 145,700 cu yds for a 2-yr period or about 73,000 cu yds per yr. The Brewerton Channel was enlarged in 1990-91, since then maintenance dredging has been extraordinarily large compared to previous requirements. Over the years 1971-86, Brewerton Channel required only 22,000 cu yds per yr compared to Tolchester Channel 1969-80 requirements of 27,000 cu yds per yr. We therefore assume that Brewerton Channel Eastern Extension maintenance dredging has been artificlally increased as a result of the channel enlargement, as mentioned in a previous section, and anticipate that it will decrease over time. The model base-channel result of 76,940 cu yds per yr appears to be reasonable.

The model was deemed to have reproduced present base-channel shoaling conditions adequately. Comparisons between base and plan channel conditions were made based on percentages of the base channel shoaling rate.

MODEL RESULTS AND DISCUSSION

The hydrodynamic model predicted that currents in the Brewerton Channel Eastern Extension would be unaffected by the widening to 600 ft. The sediment model results reflected those of the hydrodynamic model. Shoaling per unit channel area was the same in the model for existing and plan conditions. The increase in maintenance dredging was estimated to be about 20 percent, based on the additional area of the proposed channel.

Modification to the Tolchester Channel included straightening the "S-Turn" section of the channel as previously described. Sediment model runs were performed with the proposed straightened section along with the following plan variations: (1) the existing channel curve left intact, (2) the existing channel curve with a short plug installed, and (3) the existing channel curve completely filled in.

The sediment model predicted that sedimentation in the channel section south of the "S-Turn" channel section would be unaffected by the channel straightening. Most of the required maintenance dredging has been performed in the "S-Turn" channel section and the model shoaling was also greatest in this section.

The proposed straightened Tolchester Channel section shoaled more slowly than the existing curved section in the model. The overall reduction for plan variations (1) and (2) described above were estimated to be 23 and 18 percent, respectively. The reduction for plan variation (3) was markedly greater, as the straightened channel section became self-maintaining (or actually slightly erosional). The overall reduction for plan variation (3) was 59 percent.

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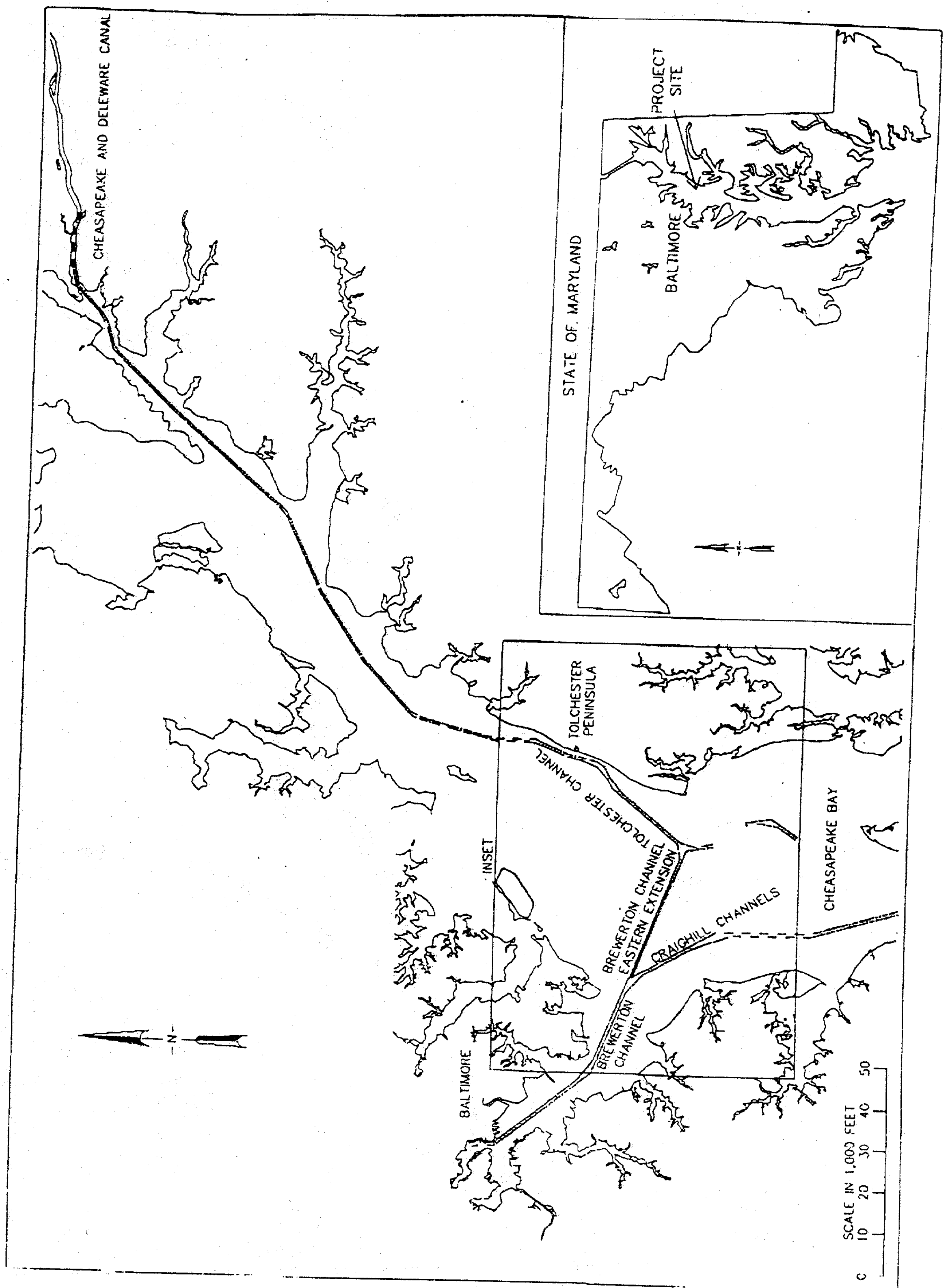
CHEASAPEAKE AND DELEWARE CANAL
PROJECT SITE
STATE OF MARYLAND
BALTIMORE
TOLCHESTER PENINSULA
TOLCHESTER CHANNEL
INSET
BREWERTON CHANNEL EASTERN EXTENSION
CRAIGHILL CHANNELS
CHEASAPEAKE BAY
BREWERTON CHANNEL
BALTIMORE
N
SCALE IN 1,000 FEET
0 10 20 30 40 50

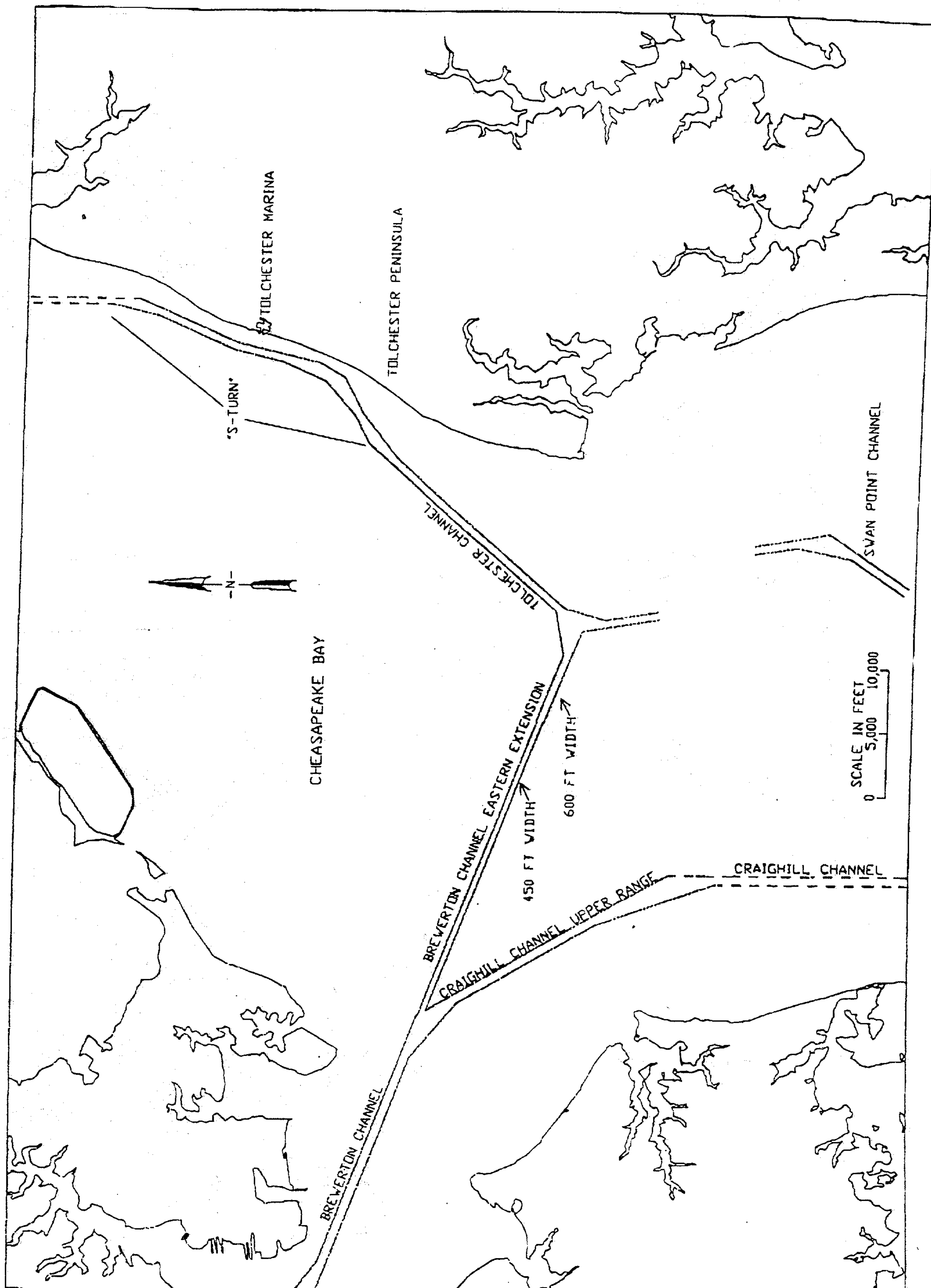

Figure A-2. Details of the study channels

C:\ORRO\CHESAP\DREDGE.WQ1\ NVOLBREWW/DIM

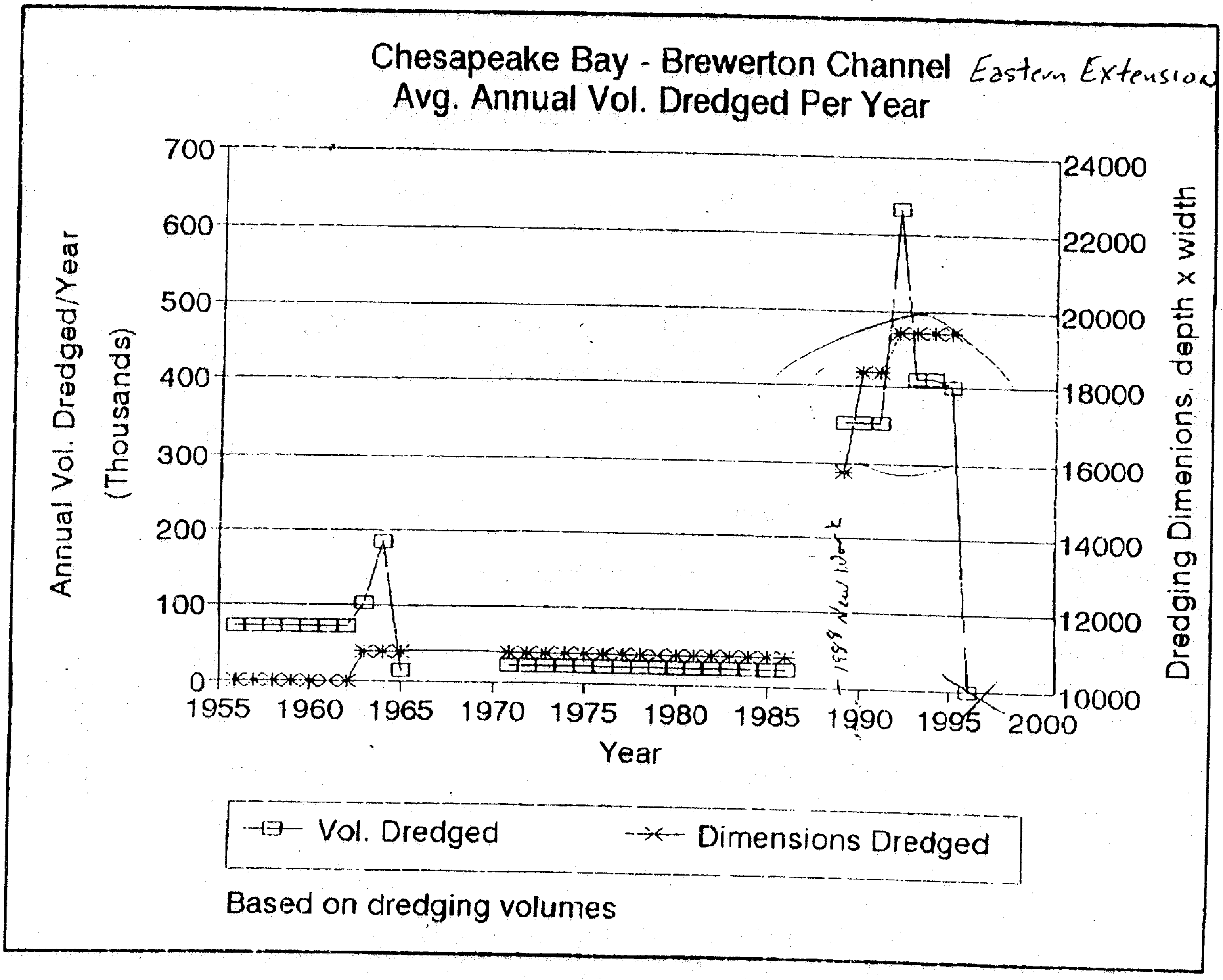

Figure A-3. Dredging and channel area history for Brewerton Channel Eastern Extension.

C:\QPRO\CHESAP\DREDGE.WQ1\ANVOL TOLW/DIM

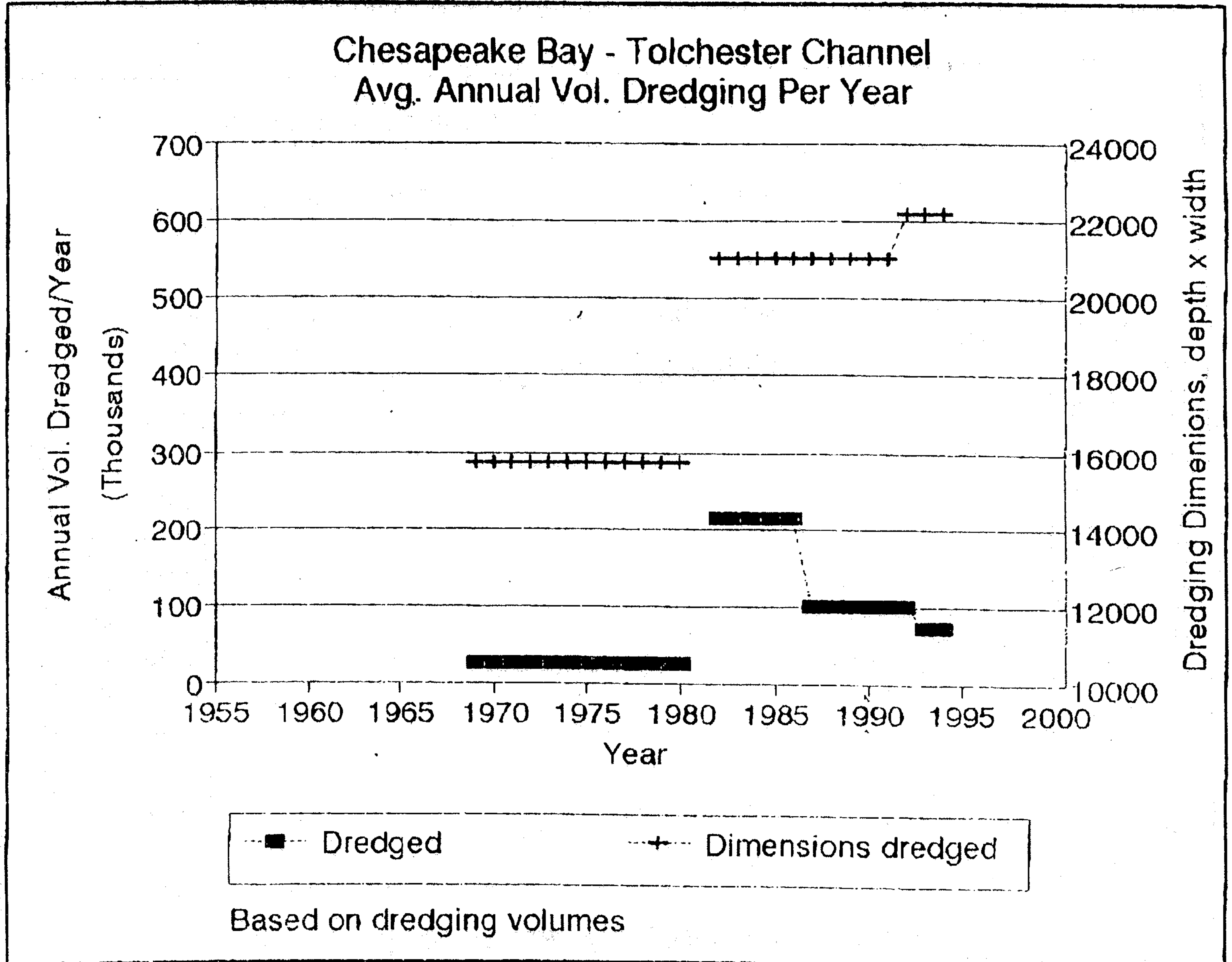

Figure A-4. Dredging and channel area history for Tolcheste Channel.

Tolchester Numerical Mesh

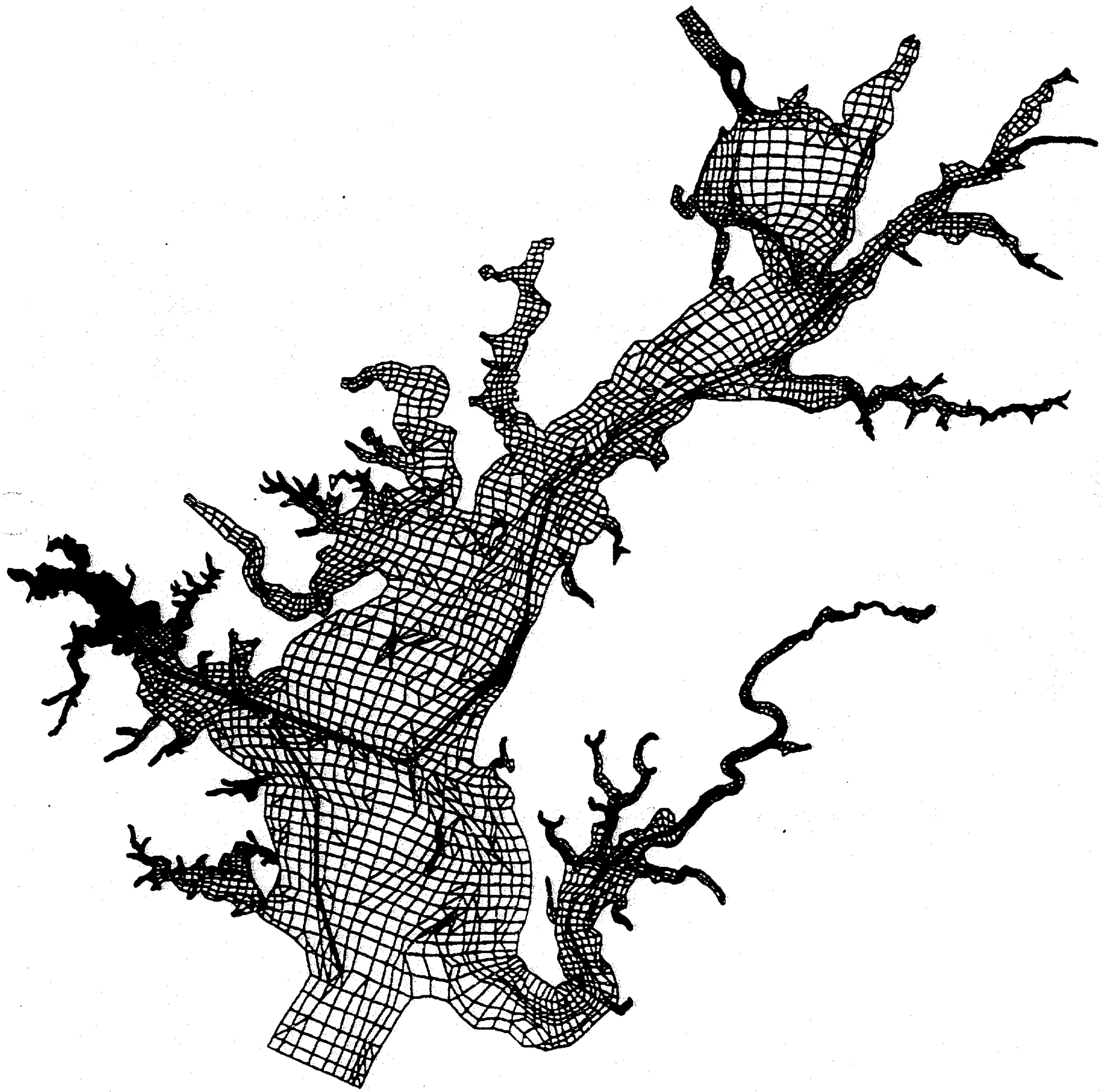

Figure A-5. Numerical mesh.

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T3
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$L2    15   0   0   75  35  45
$M     3
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SI     0
GC    10    1    8    14    19    24    29
GC    34    39    44    49
GC    6    24582    24584    24587    24590    24593    24596
CC     1   4   .12   .327   .00001
TZ   329 0.5 164 164
TT              .66
CI      1      0.008     0.49   .00006   999.0   1000.    144.    244.     -1
CI      2      0.01      0.82   .0002    999.0   1000.    288.    288.     -1
CI      3      0.05      0.96   .0002    999.0   1000.    290.    290.     -1
CI      4      0.10      2.64   .0008    999.0   1000.    340.    340.     -1
CL   1         1         4   -1
CL   1         2         3   -1
CL   1         3         2   -1
CL   1         4         1   -1
FT   1        16
HS   2
HN   1    0.0237
ED   1   35   35
IC   1       .010
WC   1   .00005
WF   0
BCL  1   .024
BCL  2   .045
END
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Figure A-6. SED2D input file.